Post-Tensioned Slabs on Ground

Part 3: Proper Detailing and Quality Control

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This is the third of four articles on post-tensioned slab on ground design and construction. This article will focus on detailing and quality control, while the previous two articles provided a general overview and special design considerations. Please see the January 2010 and April 2010 issues of STRUCTURE® magazine for these articles.

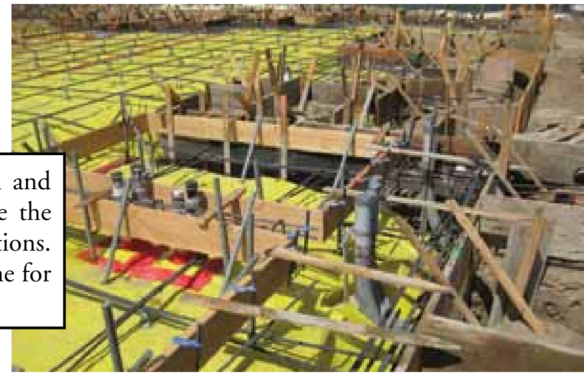

Figure 1: Trim Rebar.

Advantages in Use of Rebar

Numerical design using the Post-Tensioning Institute (PTI) method is based primarily upon on the precompression from the tendons in conjunction with the section and material properties of the concrete. Rebar plays a very limited role in the design for expansive soils, but is very useful as crack control reinforcement. Trim bars are typically placed around penetrations and re-entrant corners (*Figure 1*) where shrinkage cracks will most likely occur. Until the tendons have been stressed, the foundation is essentially unreinforced, so well placed rebar is useful in minimizing shrinkage cracks. While the force of the tendons has the potential to close up small cracks that occur prior to stressing, relying on this benefit is not recommended. The typical repair for "substantially" cracked concrete is the use of structural grade epoxy; however, this fix is often very unappealing from an owner's point of view. The crack will need to be routed out to achieve the proper width for the injector, and the epoxy rarely matches the color of the concrete. The finished repair typically looks like a spider web of dark lines, often appearing worse than the original cracked condition. The look of the repair also gives the impression that something has gone seriously wrong with the foundation. While trim rebar will not guarantee a crack free system, it will provide some crack control strength until the tendons are stressed. Rebar is also typically added under large hold downs or post loads to increase the footing's flexural and shear capacity. This is often done where the foundation design does not require the use of deep footings to resist soil movement.

Placement of Tendons

During a structural observation, the location and path of travel of the tendons should be reviewed. Localized vertical and horizontal kinks in the strands should be removed, especially if these occur near the anchor. Unless specifically detailed, the tendons should run at the center of the slab and essentially stay at this general position across the entire foundation. Chairs or dobies are typically placed at 4-foot centers to support the tendons (*Figure 2*); any vertical discontinuity in the strand is typically due to a missing or incorrect chair. Anchors that are located near penetrations should be adjusted to avoid blow outs. Provided the number of tendons installed matches the permitted plans, adjusting the location of a specific strand should not affect the performance; however, the tendons should not be placed more than 6 feet apart. If a gap larger than 6 feet is required, additional rebar or localized tendons may be required. Each tendon will be loaded to approximately 33,000 pounds during stressing, and a discontinuity near the anchor can cause cracking or a blow out. If the anchor or the penetration cannot be adjusted, schedule 40 steel sleeves have been successfully used in the past.

The observer should also verify that any rebar placed in the bottom of the footings is clear of dirt or debris. Due to the foot traffic of the contractors, it's common to have soil fall into the trench and cover the rebar. In addition to decreasing the footing depth, the soil can reduce the rebar-to-concrete bond, which will minimize its effectiveness.

Inspection

During the stressing operation, a licensed inspector is required to observe the jacking procedure and record the resulting elongations. The elongation record is the primary tool for the engineer and owner to verify permitted structural drawings have been implemented correctly. The elongation record should be sent to the engineer for review prior to removing the stressing tails. If the elongations are within 10% of the calculated value, the stressing is considered acceptable and the tails can be removed. Having the inspector list the elongation out of tolerance percentage will speed up the review process. If the elongation is outside of this tolerance, the engineer should evaluate the situation and make appropriate modifications. The author recommends taking the overall concrete section into consideration rather than focusing on a single strand.

A specific tendon only has a localized affect on the concrete for the first few feet away from the anchor, until the precompression spreads into the larger foundation area. Subgrade friction is at a minimum near the slab edge, so any reduction in the tendon force should have a negligible effect on the foundation. As

Figure 2: Plastic Chairs Used to Support the Tendons.

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the precompression force disperses into the whole foundation, the concrete isn't able to determine what strands have a "low" force and which ones have a "high" force. The concrete only feels the total load applied by the strands. Provided the overall precompression is achieved, the as-built construction satisfies the drawings and no remedial work is required. If the engineer requires the tendons to re-stressed, they will have to be de-tensioned by removing the wedges, releasing all the elongation and repeating the stressing procedure. De-tensioning can be dangerous and should only be done after careful consideration by qualified personnel. If the elongation errors are more systematic (generally high or low), the engineer may want to verify that the jack and the pressure gauge were calibrated together. The stressing unit should be treated as a complete system and not as separate pieces.

Cold Joint Hazard

In the construction of ribbed foundations, contractors will often pour the footings first, verify and make any final adjustments to the embedded hardware (*Figure 3*) and then place the slab over the existing footings. If the time gap between when the footings and slab are poured is large enough, a cold joint will be created, effectively disconnecting the slab from the footings. The foundation will essentially be a thin uniform thickness slab sitting on, but effectively not connected to, the footings. Without slab footing composite action, the section properties and flexural strength of the as-built system will be substantially less than design required. Having the tendons only being placed in the slab, the cold joint prevents their precompression from extending into the footings. The footings are basically un-reinforced concrete and more prone to cracking. Specific details and/or notes are recommended to specify the maximum time gap between pours, or verification that the separate pours were vibrated together to replicate a monolithic system. If a cold joint is desired, rebar dowels extending from the footings into the slab are typically used to achieve composite action. The dowels should be designed to transfer the horizontal shear between the footings and slab, and address any large hold downs or post loads which may require additional reinforcing. In addition, the anchor and hold down bolts may have longer embedment requirements for a two pour system.

Concrete Strength

The concrete used in a post-tensioned slab on ground is the same as conventionally reinforced foundations. The concrete will typically have a compressive strength of 2,500 to 4,500 psi. The 4,500 psi concrete is typically used

Figure 3: Adjusting a Strap in the Footing Prior to Pouring the Slab.

Figure 4: Typical Stressing Equipment.

to resist severe sulfates or is used on highly expansive sites where the higher strength can aid in satisfying allowable stresses. Some large tract home builders will require a minimum of 4,000 psi concrete with type V cement, since it provides moderate sulfate protection and sulfates have been an issue in home owner association litigation against developers and contractors. The use of higher strength concrete is typically useful for a post-tensioned foundation since the minimum compressive value to begin stressing will be achieved in a shorter time. The sooner the tendons are stressed, the sooner the primary reinforcement is added to the system which should minimize shrinkage cracks. Some engineers and contractors will perform a partial pre-stress to place some precompression in the system in an attempt to minimize cracking. The typical practice is to stress each strand to approximately 20% of the full value the day after the foundation was poured. The author would recommend caution for new post-tensioning engineers in specifying partial pre-stressing. The more times the jack is applied to the system, the greater the chance of damaging the strand, anchor, wedges or the concrete. In addition, this practice is primarily used on slab-on-ground construction and is rarely performed on elevated post-tensioned systems even though the anchors, wedges, strands and concrete are exactly the same.

Construction Joints and Delay Strips

The construction of apartment complexes and industrial projects often leads to large and sometimes irregular plate configurations. These foundations will often require construction joints and/or delay strips to create manageable pour sizes and to adequately stress the tendons. Construction joints will have the tendons continue through the joint and use shear keys with rebar dowels to connect the adjacent slabs. Ribbed foundations will typically have a center slab dowel while the thicker mat foundations will use top and bottom bars. The joints are limited to a spacing of around 100 feet which is the typical maximum length of a singled ended pull. In addition, review of the hold downs bolts and plumbing penetrations should be taken into consideration prior to selecting a joint location. Placing a joint directly adjacent to a large uplift/post load or splitting a penetration is not recommended.

Delay strips are typically three feet wide open spaces between slab pours so the tendons from each pour can be stressed. The rebar is lapped for the full width of the pour strip but should not extend into the adjacent slab. Any rebar extending from one pour to the other will act as a tension tie and eliminate any independent movement of the slabs. The time the delay strip is poured is at the engineer's discretion, but is typically around 30 to 45 days to allow the adjacent pours to shrink as a smaller unit rather than be part of a larger plate. Near the end of the project, the concrete sub-contractor will often request to place the delay strip before the recommended time as occurred. From a structural point of view, there is minimal downside since the strength is not affected; however, it's important that owner and architect understand additional shrinkage cracking may occur.

Tendon Length

Tendons can be manufactured to effectively any length desired but practically range from 20 to 200 feet long. Tendons less than 20 feet long will have a very small elongation and this increases the chance of over extending the jack, over loading the tendon and possibly cracking the slab. For smaller slab areas, rebar is recommended instead of using short tendons. The maximum length of a tendon is typically around 200 feet, due to stressing limitations and realistic pour sizes. While it's possible to use longer tendons, the buildup of subgrade friction and increased shrinkage crack potential usually makes this practice uneconomical. Tendons longer than 100 feet often require double ended pulls, unless specifically designed otherwise. Double ended pulls require stressing at each end of the strand, but the stressing is not done simultaneously. The stressing system (*Figure 4*) is placed on one end while the wedges are hammered into the opposite anchor to resist the stressing force. The jack will be fully elongated at the one end and will generate the vast majority of the required elongation. After the wedges are installed on the first stressing end, the jack is removed and placed on the other end of the tendon. The jack is loaded to the same pressure as the first stressing, but a very small elongation is expected. This second stressing is referred to as a "lift off", and is primarily intended to relieve any slack or extra friction in the strand and to seat the wedges to correct gauge pressure. A double ended pull is typically indicated by arrow heads on both ends of the strand. If the tendon location and stressing is left up to the contractor or supplier, notes requiring double ended pulls for tendons beyond a certain length are recommended.

For these larger foundations, it is recommended that the designer consult the concrete sub contractor to determine their preferred pour size and stressing abilities. Unlike rebar only foundations, the pour size and stressing locations should be determine during the design process so the appropriate number of tendons are specified.

New Footing Requirements

With the new ACI appendix D requirements for the design of concrete due to uplift loads, the typical footing details that have been used for years will most likely not be sufficient. Additional width and depth of the footings are typically required at the hold down bolts. If the building structural engineer is detailing the framing to concrete connection, notes are recommended on the post-tensioning plans to direct the contractor to the other engineer's drawings for the additional footing requirements.▪

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