Post -Tensioned Slabs on Ground

Part 2: Specific Design Considerations

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The January 2010 issue of Structure Magazine contained a general overview of the design and construction of post-tensioned slab on ground foundations. This article will focuses on specific engineering items that occur when designing these types of foundations. As described previously, post-tensioned slabs on grade are primarily designed to support residential and light industrial construction that is on expansive or compressible soil. The foundations can be designed per the Post-Tensioning Institute (PTI) method to be a ribbed or uniform thickness foundation.

Figure 1: Ribbed Post-Tensioned Foundation.

Ribbed Foundations

A typical ribbed foundation will have a 5-inch thick slab, with interior and exterior footings that extend from one end of the foundation to the other (*Figure 1*). The layout of the footings (ribs) will give it an exaggerated waffle slab appearance if it could be viewed from the soils perspective. Due to their depth, the footings will provide the vast majority of the foundations section modulus and moment of inertia, which are the key parameters in limiting the flexural stresses and deflections. Although it may be economically advantageous to have a few very deep footings to generate the same elastic section properties, the performance of the foundation may suffer with large gaps between ribs. The PTI method limits the maximum spacing of footings to be 15 feet, and requires the spacing of adjacent footings to be 20% of each other. The spacing limitations are intended to have the footings close enough such that the foundation can respond as having a consistent stiffness across its cross section, rather than having localized areas of large stiffness that are connected by a relatively thin slab. In typical structures, the footings are around 10 to 12 feet on center in each direction. A tighter rib spacing will also minimize footing depth and width. In the author's opinion, the footings should be located under the lateral system and the load bearing elements (walls, post or columns). In addition to providing vertical and lateral support for the structure, the footings location will be linked to the architectural plans which will minimize dimensional discrepancies in the between the structural and architectural drawings.

The footing width and depth will depend on the specific site conditions and the load of the structure, but they are typically around 18 to 24 inches deep (including the slab thickness) and 12 inches wide. Footings that are wider than 14 inches can be constructed, but the width is limited to 14 inches for the numerical design.

Footings of different depths can be used, but the ratio of largest to smallest must be kept within 1.2. This is most typically seen where deeper footings are used on the perimeter due to larger post loads/hold downs forces, or specific embedment requirements of the soils report. Although the foundation will benefit from deeper footings, the code limits the numerical design to the 1.2 ratio. Using very deep exterior footings to generate section proprieties that satisfy stress limits, such that interior footings are not required or are very shallow, is not the intent of the methodology.

Instead of adding ribs for bearing wall loads, the PTI method contains a procedure for the slab to act as a footing. A typical post-tensioned 5-inch slab with a compressive strength of 3000 psi and a precompression force of 50 pounds per square inch (code minimum) can support a 1,900 pound per linear foot bearing wall. This capacity can be increased with thicker slabs, higher strength concrete or a larger precompression force from the strands. In most residential construction, footings are not required to support the bearing wall loads. The potential to have the slab act as a footing is also useful in home remodels or tenant improvements, since the requirement for new footings can be minimized. The same philosophy can be used for the slab to resist post loads. For most code compliant designs, a post-tensioned slab can comfortably resist 1,000 pounds of load for each inch of thickness.

For typical single family home construction, the tendons in a ribbed system are approximately 3 to 4 feet on center in each direction. This spacing allows easier installation and inspection while minimizing the potential of field personnel damaging the strands or pushing them off their supports. In addition, the relatively large spacing typically provides sufficient room for plumbing and other penetrations without modification to the tendons. The spacing of the tendon is not required to be placed at a specific spacing. Variations in the tendon locations, to avoid penetrations, re-entrant corners or hold downs, are permitted provided the spacing between adjacent strands is less than 6 feet. If a spacing of 6 feet is required, additional rebar may be required for crack control and continuity of the foundation.

The number of strands is primarily affected by the desired precompression force and the sub grade friction resistance. For the same site conditions and construction, a larger footprint foundation will have more tendons since the sub grade friction force increases with size. The code minimum precompression of 50 psi is calculated at the middle of the foundation, where the affect of sub grade friction is the largest. For larger foundations, there will most likely be a substantial difference between the precompression force at the edge of the foundation compared to the middle.

The tendons in the majority of post-tensioned foundations are located in the center of the slab and run flat from anchor to anchor. Care should be taken by the contractor and deputy inspector to eliminate localized kinks (vertical and horizontal) in the strands when they extend over footings or where they are curved to avoid penetrations. The strands are intended primarily to provide a precompression force throughout the foundation to reduce flexural tension stresses. They are not designed as tension reinforcement that conforms to the moment diagram as they would in elevated slab and beam design. The design of these foundations is based solely on allowable stresses, so placing the tendons at different locations of the slab will not provide in any benefit in the design. Balance loads created by vertically draping the tendons aren't required since the structure is supported by the soil. In addition, since the expansive soil movement can occur in both vertical directions, load balancing may help in one condition while hurt the system in the other. Even though load balancing is the primary benefit of post-tensioning in elevated slab and beam design, it should play no part in the design of these ground supported foundations. In some extreme edge lift cases, specific tendons are anchored at the mid-depth of the slab and immediately draped to the bottom of the footing, where they extend across the foundation until they are draped back up at the other end of the foundation. This profile will create a "downturned" force that is intended to counteract the force of the soil moving "upwards". This type of design is primarily done in Texas where they have very large edge lift conditions. Even with expansive soils, everything is larger in Texas.

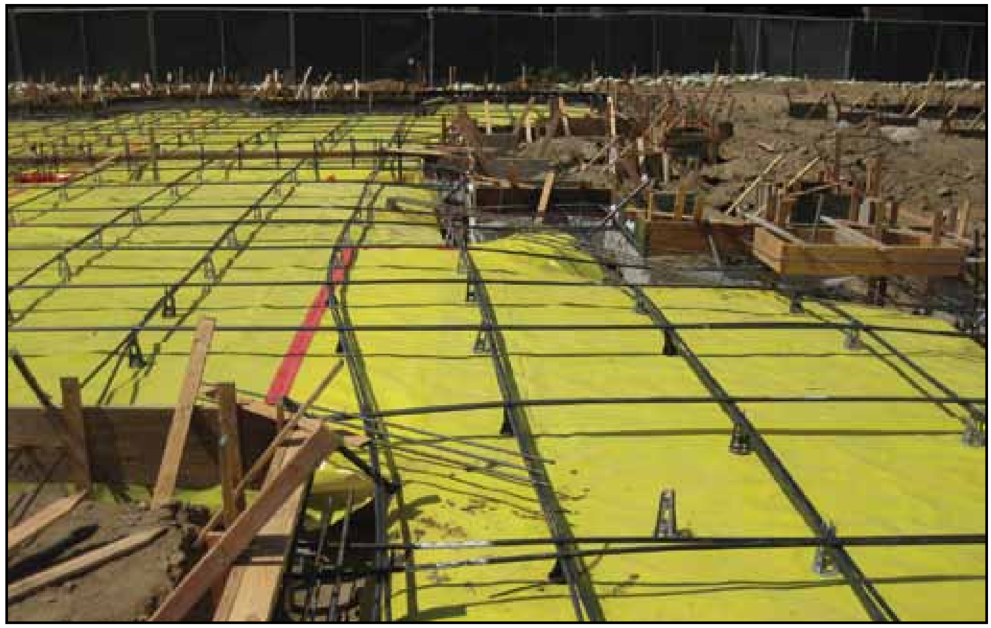

Figure 2: Uniform Thickness Post-Tensioned Foundation.

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Uniform Thickness

The uniform thickness option is designed by converting the section properties of the code compliant design ribbed foundation to a single thickness slab. The conversion is intended for the slab only, and does account for the presence of exterior footings. Using the section properties of the exterior footing to minimize the uniform slab thickness is not the intent of the PTI method or the building code. Without interior footings, the slab alone will be required to provide the stiffness and strength to resist expansive and compressible soil movement. Perimeter footings are often requirements of the soils report or to resist large post or hold down loads, but since their stiffness cannot effectively be distributed over the entire foundation, their influence is to be ignored in the conversion.

Typical uniform thickness slabs are in the 8 to 12 inch range (*Figure 2, page 9*) and have been used to support up to 5 stories of wood frame construction. They typically have more concrete when compared to a ribbed foundation, so more tendons are required to provide the required precompression. Without interior footings, deepened sections of concrete may be required to resist large post loads or shear wall hold downs. Depending on slab thickness, localized footings are often used under the lateral system to satisfy the allowable soil pressure due to overturning.

Regardless of the slab thickness, the tendons are still located and anchored in the middle of slab. This layout can create slabs with 5 to 6 inches of cover from the strands to the top of the concrete. Although this would not be permitted in elevated slabs, there is no additional top rebar required in these types of foundations. Some engineers will place a grid of rebar or mesh in the top of the slab, but this is not a requirement of the PTI method and may be done simply for crack control. In the larger foundation plates, tendons can have a required spacing of 12 to 24 inches on center. To maximize the distance between strands, the tendons can be grouped into bundles of twos or threes. The bundled strands are placed side by side, are typically tied together, and use the same chairs or dobies for support. They are separated near the slab edge or stressing location to allow for the installation of the individual anchors. In addition, this practice will minimize having a series of tendons that are varying lengths if the slab edge has an angled or saw tooth configuration.

Figure 4: Saw Cuts on a Uniform Thickness Foundation.

Figure 3: Encapsulated Tendon with a Pocket Former.

Cost a Factor

For engineers and contractors that are new to post-tensioned foundations, a common question is what type of foundation is best suited for my project? As in most situations in construction, the contractor's price is typically the deciding factor. With the ribbed system, more trenching is required, and this has been a cost and time issue for some contractors. In addition, the ribs require maintenance during the placement of the reinforcing and the vapor retarded. Portions of the soil may drop into the trench during construction, affecting the footing depth and covering the rebar with dirt. The uniform thickness foundations will have less trenching but more material costs in concrete and tendons. If you are dealing with methane issues, the uniform thickness slab option is typically preferred since it's more economical to install the barrier relatively flat rather than extending it through a series of overlapping footings. In the author's experience, most single family homes are constructed with a ribbed foundation, while multi-level apartment/condominium projects are designed with a uniform thickness system.

Corrosion

For post-tensioned slabs on grade, the soils report should include information regarding the corrosiveness or the chloride content of the site. For corrosive sites, encapsulated tendons (*Figure 3*) are used to further protect the strand, anchor and wedges from deterioration. The strand, anchor and wedges are the same between the standard and encapsulated system; only the sheathing and the anchor covering is changed. The anchor assembly is encased in a watertight connection between the strand, sheathing, anchor and wedges. Standard encapsulated systems are hydrostatically tested to verify water tightness. For this reason, tears in the sheathing, regardless of length need, to be repaired and anchors that arrive on site in a damaged condition need immediate attention. Sealing the encapsulated system after the tendons have been exposed to an aggressive environment will only lock the corrosive elements into the system, increasing the likelihood of damage. Unlike the sulfate table in ACI 318, there is no corresponding corrosive chart that identifies when encapsulated tendons should be used. Per the PTI recommendations, if the soils report lists moderate or above chloride content or if the report lists the site as corrosive to ferrous metals (or other similar language), encapsulated tendons should be specified on the structural drawings.

Shrinkage

To minimize shrinkage cracks, it is critical that the tendons are stressed as soon as possible. The PTI design manual recommends the tendons be stressed within 10 days of placing the concrete. The precompression from the strands is the primary crack control reinforcement in the foundation. The sooner the strands are stressed, the sooner the slab can resist the tensile stresses generated from the shrinkage of the concrete. These foundations will typically have very little rebar, so until the tendons are stressed, the concrete is essentially un-reinforced and prone to cracking. To further resist shrinkage cracking, some engineers will saw cut the slab within the first 24 hours after placing the concrete (*Figure 4*). The depth and spacing of the saw cuts will vary depending on the slab thickness so the tendons will not be damaged during construction. In addition, the saw cuts need to be specified such that the continuity of the slab is not significantly impacted.▪

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