General Considerations for Post-Tensioned Slabs on Ground

By Bryan Allred, S.E.

Figure 2: Post-Tensioned Ribbed Foundation.

Post-tensioned slabs on ground have been successfully used for decades, and are typically associated with the foundation system for one and two story wood structures. If you live in the southwestern part of the United States and bought a house in the last twenty years, there is a very good chance you live on a post-tensioned foundation. In addition to residential construction, the use of post-tensioned foundations has expanded to support 4 and 5 story wood structures, steel and wood commercial buildings and concrete tilt ups. Post-tensioned slabs on ground have also been used for industrial floors where levelness is critical for sensitive industrial machinery to function properly. Aside from supporting larger loads, the size of commercial foundations can easily increase to the point where pour strips or construction joints are required. While post-tensioned slabs on ground have been used for decades, there are numerous misconceptions about these types of foundations that have confused engineers, inspectors and building official alike. Understanding what a post-tensioned slab on grade can accomplish is critical to designing a well performing and code compliant foundation.

The Post-Tensioning Institute (PTI) has developed a methodology over the years for resisting the moments and shears developed from expansive and compressive soil. The PTI method has been a part of the previous editions of the *Uniform Building Code* (UBC) and the current version of the *International Building Code* (IBC) in section 1805.8.2. The PTI method was originally developed for buildings with the majority of the structure supported by perimeter walls having loads up to 1500 pounds per linear foot (plf). Post-tensioned foundations have been successfully used for structures having 2,500 plf perimeter loads, but engineering judgment should be always be used for buildings that have loads larger than 1,500 plf. Even though these foundations are supporting the weight of the structure, they are not considered structural members in that they don't need to conform to the requirements of ACI 318. This is stated in ACI 318-08 Section 1.1.7 and R1.1.7. The primary post-tensioning difference between slabs on ground and structural slabs is that these foundations are required to have a minimum of 50 pounds per square inch (psi) of pre-compression after losses and subgrade friction. This pre-compression value is substantially less than the 100 and 125 psi minimums required in elevated one and two way slabs respectively. In addition, there is no ultimate strength design for slabs on grade. The entire design is based upon an allowable stress and serviceability approach.

Post-tensioned slabs on ground typically use ½-inch diameter, 7-wire strands that have an ultimate strength of 270 kips per square inch (ksi) (*Figure 1*). Each strand is anchored with a ductile iron casting that transfers the force from the strand into the surrounding concrete. For proper performance, it is critical that the concrete adjacent to the anchor is well vibrated and free of obstructions. Each tendon will be loaded to approximately 33,000 pounds at stressing. Slab cracking or blow outs can occur if rock pockets, honeycombs or discontinuities in the concrete exist that prevent the foundation from resisting this large concentrated load. A PTI method foundation is either designed as a ribbed system or a uniform thickness mat (*Figures 2* and *3*). The ribbed system uses a relatively thin slab with interior footings to add strength and stiffness. The slab is typically about 5 inches thick, with the footings spaced in each direction at approximately 12 feet on center. The footings are typically between 18 to 24 inches deep and are often aligned with the columns, bearing walls or the lateral system. The tendons are spaced between 3 to 4 feet on center in each direction, which essentially eliminates conflicts with plumbing and other penetrations.

The uniform thickness mat uses the code compliant ribbed design and converts it into a thicker slab that matches the section properties of the ribbed system. The mat slab will typically be in the 8- to 12-inch thickness range. The uniform thickness mat will have more concrete than a ribbed system, so a tighter spacing of the tendons should be expected. Even though it is not considered in the conversion calculation, the mat will have a perimeter footing that can be used to resist vertical and lateral

Figure 1: Standard Post-Tensioning 7 Wire Strand and Anchor.

Figure 3: Uniform Thickness Mat Foundation.

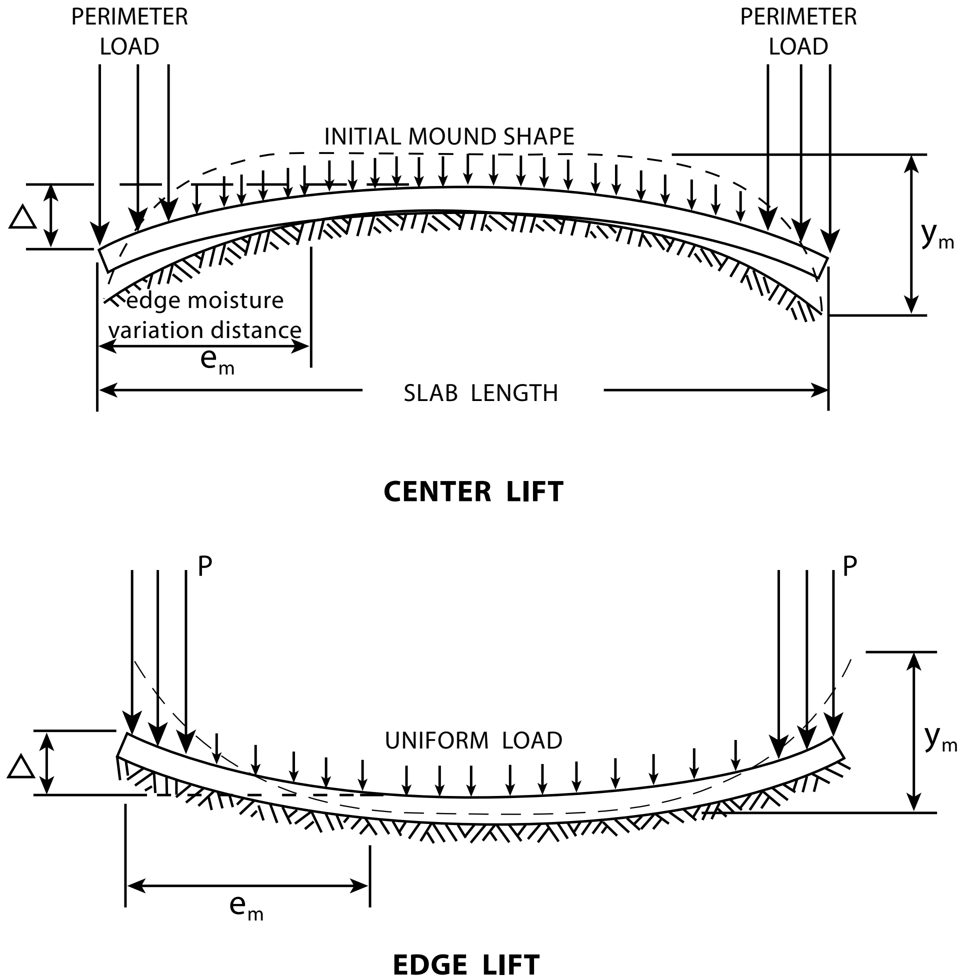

Figure 4: PTI Design Parameters.

loads, but will also provide some protection for water intrusion under the structure. Depending on the mat slab thickness, localized interior footings may be required under heavily loaded shear walls or columns.

For both systems, a vapor retarder is typically placed beneath the concrete to minimize moisture intrusion into the structure. Depending on the recommendations of the geotechnical engineer, layers of sand or gravel can be placed below or above the vapor retarder. In most applications, a single layer of 6 or 10 mil visqueen is used as the vapor retarder.

Unlike elevated slabs and beams where the tendons are draped to push back against the weight of the building, the tendons in a slab on grade typically run flat at the center of the slab. The inspector, contractor and structural observer should verify that no localized "kinks" are occurring along the tendons' path of travel. When a "kinked" tendon is stressed, the draped portion will try to straighten out and the upward force may be large enough to crack or push up the top of the slab. The tendons can curve horizontally to miss penetration or other embedded hardware, but the curve should always be done in a gradual manner to prevent kinks or sharp bends in the strand. In addition, the curve should occur several feet away from the anchor. To facilitate proper stressing, the strand should extend straight into the anchor to minimize any grinding against the steel that could possibly damage the individual wires.

The main engineering benefit of post-tensioning is the pre-compression that is used to reduce the flexural stresses (M/S +/- P/A) created by the soil. Instead of increasing the section modulus by adding concrete or using a higher compressive strength mix, which will typically increase the cost of the foundation, the pre-compression can reduce the flexural stress to be within allowable limits. While the pre-compression force is a useful design tool, too much post-tensioning has the potential to cause additional cracking and shrinkage in the slab. A typical design pre-compression range is between 60 to 100 psi, after losses and subgrade friction. Anything substantially over 100 psi may indicate your slab thickness, footing depth or quantity of footings needs to be re-evaluated. The primary benefit of post-tensioning to the owner is cost savings. A post-tensioned slab on ground will typically be thinner and have less reinforcing steel than a conventionally reinforced-only foundation that has been code compliantly designed to resist expansive soils.

While it's not required to fully comprehend the mechanics of expansive soils, it helps to have a basic understanding of their nature to better understand what the foundation is trying to resist. Expansive soils have the potential to expand or compress due to changes in water content in the soil. During periods of large rain fall, the soil can expand thereby pushing up the edge of the structure. The majority of the movement will occur near the edge of the foundation where the increase in water content is the largest. During periods of little or no rain fall, the soil can compress and the foundation will either "drop" with the soil or cantilever off the soil that has not been affected. *Figure 4* demonstrates the action of the soils and the resulting affects on the foundation for the center lift and edge lift conditions that are the basis for the PTI method. Edge lift applies when the soil expands, while center lift occurs when the soils dries and compresses. The main cause of movement is the change in water content. Typically areas that have clayey type soils and large fluctuations in water content are most susceptible to movement. Areas that have consistent rain fall all year long, whether that is substantial or very little rain fall, have minimal affects since the soil has essentially a consistent moisture content through the life of the structure. The most affected areas have very dry months followed by very rainy months. Texas typically experiences the largest expansive soil movement due to their dry and wet climates, coupled with their clayey type soil.

To design a post-tensioned slab on ground, the geotechnical engineer needs to provide the structural engineer with additional information beyond bearing pressure and minimum embed requirements. Values for Em and Ym are the primary values used in the design. Em (*Figure 4*), edge moisture variation distance, is the distance over which the moisture content of the soil varies. Em is measured from the slab edge into the structure. The further inside the building you are, the less affect the climate should have on the site's water content. The Em value is typically in the 2- to 5-foot range. The Ym value (*Figure 4*) is the expected amount of differential soil movement due to the increase in water content. The Ym is typically in the 0.5- to 3-inch range. For the PTI method, the maximum value of Ym is 4 inches. For soils that have a Ym value over 4 inches, another foundation type or analysis system may need to be considered. While the equations of the PTI method can be used for any numerical value, engineering judgment should be used when

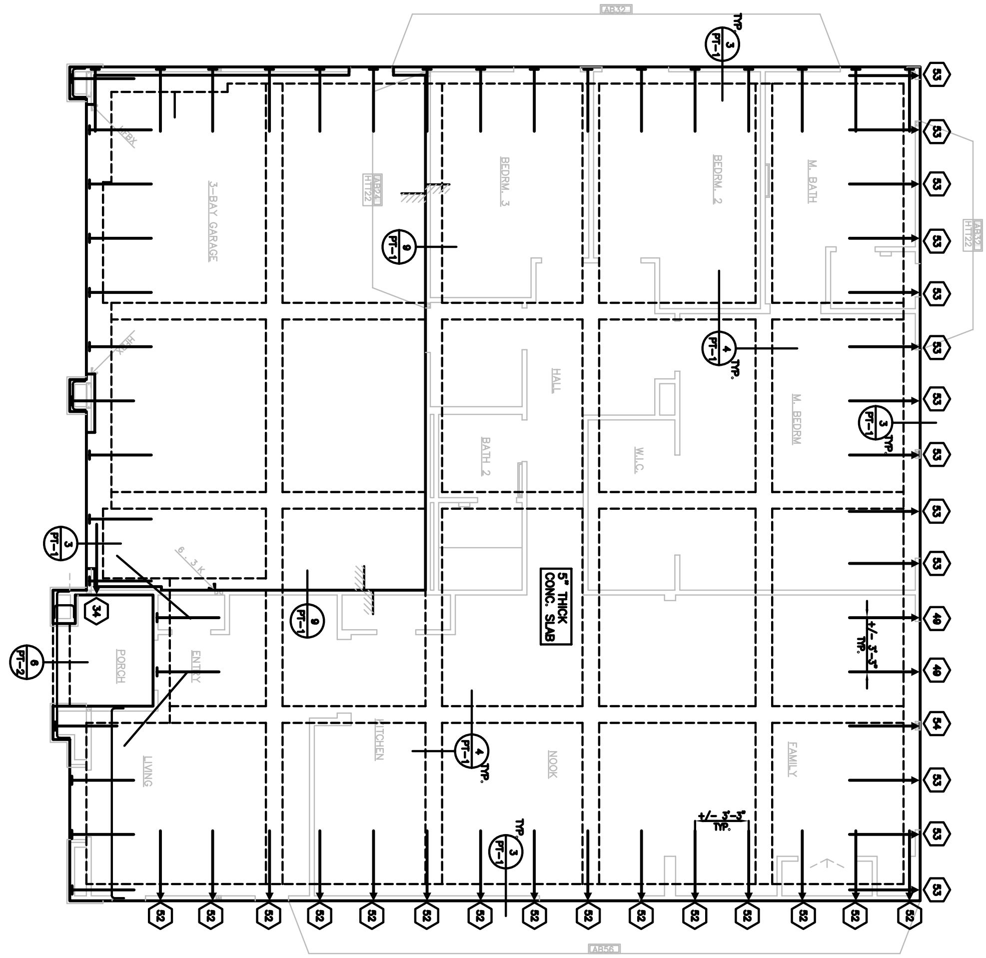

Figure 5: Typical Post-Tensioned Slab on Ground Plan.

the potential upward movement is above 4 inches. Both Em and Ym are measured off the climate conditions alone and do not account the property's owner choice of landscaping or irrigation. There is no realistic way a design consultant can predict the actions of the owner and the maintenance of the site. In addition to the PTI values, the soils report should include the suflate and chloride/corrosive content of the site. Per ACI 318-08 table 4.3.1, the sulfate content affects the compressive strength of the concrete, type of cement used and the water cement ratio. A moderate or above chloride content will determine if the tendons need to be encapsulated. An encapsulated tendon uses a thicker sheathing over the strand, and covers the anchor with a plastic boot to isolate the anchor and wedges from the environment and possible corrosion.

Many of the first firms to design post-tensioned slabs on ground originated from the post-tensioning supply or contracting industry. With their particular experience, the first p/t slab on ground drawings were created as more of a shop drawing than a typical design drawing. A shop drawing version of a post-tensioned foundation plan (*Figure 5*) will have each strand located on plan, its length called out including the tail(s) for stressing and a color code that corresponds to its anticipated elongation. With this configuration, the plan could be sent to the supplier for fabrication without involving the traditional shop drawings phase of transforming the structural drawings into a fabrication list. Without the need for separate shop drawings, the inspector can use the structural drawings to determine if the tendon's layout and elongations meet the requirements of the structural engineer. In addition, this practice speeds up construction and minimizes any errors in creating the shop drawings.

Some engineering firms have moved away from this practice and simply indicate the total number of strands that are required in each direction, and leave the specific placement and tendon lengths to the contractor. Depending on the slab configuration, the tendons may be grouped into parts of the foundation so a different spacing can be used, but the plans stop short of locating or identifying the strands. This practice is similar to elevated slabs; however, it should be noted that listing the tendons by a force is not recommended. Due to the subgrade friction effect, the compression in the concrete will significantly vary between the anchor and the midpoint of the slab. If a kips per foot number is used (similar to elevated slabs), it would be unclear if that reference is relative to the final effective force or the stressing force. In addition, the tendon supplier would essentially have to re-design the foundation to determine the subgrade friction and the affect on the strands. The primary difference between the two systems is that shop drawings will need to be created for the latter and be reviewed by the structural engineer. From the author's experience with other engineers in different parts of the U.S., it seems that each region has developed their own standard of practice for post-tensioned slabs on ground; however the shop drawing approach is more typically used.

The designs of post-tensioned slabs on ground are often done by a specialty engineering firm or a design build contractor that will most likely not participate in the design of the super structure. With two engineering firms involved, there can be a potential issue involving where one engineer's responsibility ends and the other begins. In the author's opinion, the super structure engineer is required to provide the vertical and lateral loads that the foundation will support and the connection details that are able to transfer the loads into the concrete. With the loads and connections established, the post-tensioning engineer is responsible for providing a foundation that can resist the entire vertical and lateral load from the structure, in conjunction with the forces from possible soil movement. The scope of work between both structural engineers should be clearly outlined prior to creating construction documents to avoid any confusion on limits of responsibility. The PTI method is based solely on dead and live loads, and doesn't contain a specific design for lateral forces. Post-tensioning essentially provides no reduction in the footing dimensions for satisfying allowable soil pressure due to overturning forces.

This is the first in a series of articles describing the engineering and construction of post-tensioned slabs on ground. Future articles will explore some of the more specific engineering and construction aspects such as structural design and detailing, quality control, post-construction maintenance/repair and how to make modifications to an existing post-tensioned foundation.▪

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