VIEWPOINT

CREATING OPENINGS IN UNBONDED POST-TENSIONED SLABS

BY DON KLINE

It is often necessary to create openings in existing concrete slabs. Openings may be large, such as those required for a new stairway, or small core penetrations, such as those required for plumbing risers. Post-tensioned (PT) slabs have the added complexity in that PT strands may have to be cut. It is a common misconception that creating openings in existing PT slabs is difficult, expensive, and dangerous. This perception is perpetuated because the field procedures and hardware used to create these penetrations are not fully understood. This concern is sometimes given as a reason for avoiding PT construction in particular applications.

Cutting openings in PT slabs does require care and caution because of the possibility that PT tendons may have to be cut. However, with the proper knowledge of structural behavior, repair hardware, and PT field practices, retrofitting openings and other penetrations in PT slabs is not only feasible but can also be achieved safely and economically.

TYPES OF OPENINGS AND PENETRATIONS

There are two types of openings that are commonly cut into existing slabs: small penetrations and large openings. Small penetrations are those that can be cut into a slab without affecting any of the existing PT tendons; conversely, large openings are those that require the cutting of existing tendons.

SMALL PENETRATIONS

As a general rule, it can be assumed that the effect of small penetrations will be negligible and that the slab will behave similar to the slab without penetrations, provided that:

1. None of the existing PT strands are cut during the coring of the penetration;
2. The opening is located not less than 10 times the slab thickness from a supporting column;
3. The opening is not located near a concentrated load; and
4. The opening or group of openings does not significantly reduce the effective flange area for a supporting beam.

When applying this general rule, good judgment should be exercised. A large number of small openings in a concentrated area can have a significant effect on slab strength and stiffness, particularly if several reinforcing bars are cut.

Prior to cutting small penetrations in a PT slab, existing PT strands should be located using nondestructive testing (NDT) equipment such as ground-penetrating radar (GPR).[1] Once the strands have been located and marked on the slab, small penetrations can be made using core-drilling equipment or chipping hammers.

LARGE OPENINGS

Sometimes it is necessary to create large openings in a slab for stairwells or large duct shafts between floors. Creating a large opening in a PT slab will result in several PT strands being interrupted by the new opening. An engineer should be consulted to analyze the effect that the new opening will have on the slab. The slab with the new opening should be analyzed in accordance with ACI 318-08,[2] Section 13.4.1. The analysis should show that strength is adequate and that all serviceability conditions, including stress limitations and deflections, are met.

ACI 318-08,[2] Section 13.4.2, allows for the creation of openings in existing slabs without the need for special analysis; however, it requires that an amount of reinforcement equivalent to the amount that is interrupted by the opening be added on either side of the opening. Hence, in lieu of special analysis, slab strengthening would be required to restore the original reinforcing and this would be required whether the slab is reinforced with mild steel or post-tensioning.

It is important for the design team to understand the implications of locating new openings in certain critical regions. Bhatti et al.[3] discussed how large openings can be cut in certain regions of the slab without adversely affecting structural safety, serviceability, and integrity. For two-way flat plates and flat slabs, the most desirable region for openings is at the intersection of the two orthogonal middle strips (Area 1 in Fig. 1). The least desirable location is adjacent to a column, where punching shear capacity can be severely reduced (Area 3 in Fig. 1). Although column strips and middle strips are not commonly used in PT design, these terms, as defined in ACI 318-08,[2] Chapter 13, are useful for identifying regions in a two-way slab panel.

For large openings, the general tasks associated with the planning and creation of an opening are:
1. Select the location for the new opening.
2. Evaluate the structural adequacy of the slab in its final state with the opening. Design a slab strengthening solution, if required.
3. Evaluate the structural capacity of the slab during intermediate stages of construction. Design temporary shoring, if required.
4. Install shoring, if required.
5. Identify locations of existing PT strands that intersect the new opening.
6. Detension and reanchor strands at the perimeter of the new opening.
7. Remove concrete from the opening.
8. Strengthen the slab, if required.

To ensure successful execution of any retrofit project, it is vital that each member of the project team (architect/engineer, contractor, and specialty PT contractor) clearly understands who is responsible for completing the tasks listed previously.

SLAB STRENGTHENING OPTIONS

The structural analysis will determine if strengthening is required for the slab. Strengthening of the slab can be achieved by[4]:

- Span shortening: Creating new intermediate supports to reduce span length.
- Section enlargements: Increasing the slab depth or adding a concrete beam to increase strength and stiffness.
- Externally bonded reinforcement: Bonding steel plates or fiber-reinforced polymer (FRP) to the slab can create a new composite section that increases strength and stiffness.
- External post-tensioning: Providing additional prestress force into the slab using post-tensioning that is external to the slab.

TYPICAL SLAB OPENING PROCEDURE

The following discussion provides a typical approach that should be used to create openings in PT slabs. This procedure may vary depending on many factors. Some of the variations are highlighted in the discussion.

Step 1: The perimeter of the opening is marked on the top and bottom of the existing slab.

Step 2: Shoring is installed under the opening and extended several feet beyond the perimeter of the opening in each direction. Shoring is also placed below the opening to prevent debris from falling to the level below during demolition.

Step 3: PT strands intersecting with the opening are located using NDT methods such as GPR.

Step 4: Prior to beginning detensioning of the strands, the specialty post-tensioning contractor should take appropriate measures to ensure the safety of the public and mitigate risk to property.

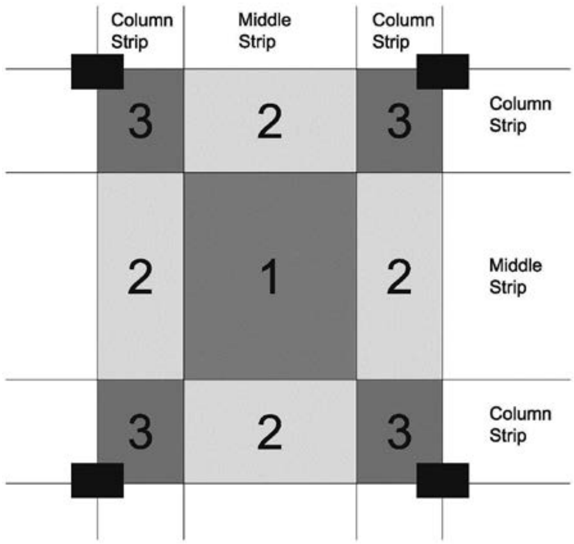

Fig. 1: Areas for slab openings

Fig. 2: PT strands are cut using a grinder

Small detensioning pockets are chipped into the slab, exposing the strands using chipping hammers. The strands are then individually detensioned using a handheld grinder (Fig. 2). PT strands are typically detensioned in phases to minimize the loss of prestress at any given time during construction.

Oxyacetylene torch heating is another effective method that can be used to detension tendons. When the torch method is used correctly, the flame does not actually cut through the strand. Instead, heat from the flame causes the individual wires to yield and elongate. Eventually, the wires begin to rupture, thereby reducing the amount of energy released as the strand is severed.

Detensioning by means of a grinder, saw, or torch results in a sudden release of energy in the slab. The magnitude of the energy release is directly proportional to the length of the tendon that is being detensioned and can be significantly affected by the locations of intermediate anchorages, type of intermediate anchorage used, and direction of the intermediate anchorage.

There are various techniques that can be employed to protect property and the public from potential hazards during the detensioning operation. Some of these techniques include:

Fig. 3: Anchorage pockets being chipped out

Fig. 4: Anchorage pocket after chipping

a. Using a detensioning collar to temporarily lock off the strand at a predetermined location in the slab (normally at the boundary of the new opening). Although detensioning collars can be a very effective means of eliminating the sudden release of energy during detensioning, they cannot be used in situations where strands are grouped or bundled together.

b. Using a specially designed detensioning jack to release the force in the strands in a controlled manner.[5]

c. Installing a barrier at the slab edge to prevent the strand and grout plug from becoming projectiles during detensioning operations.

Step 5: New anchorage pockets are chipped in the slab at the intersection of the strand groups and the perimeter of the opening (Fig. 3). The width and length of the pockets depends on the number of stands in the group and the location of the new anchorage relative to the strand profile's high and low points (Fig. 4). If the new anchorage is near a strand high point, then the pocket will have to be long enough to allow the strand to be reprofiled so that the new anchorage can be located at the middepth of the slab.

Fig. 5: Installation of reinforcement for anchorage pocket

Fig. 6: Tying steel at anchorage point

Fig. 7: Pouring anchorage pocket

Step 6: New PT anchorages are placed in the pockets along with the appropriate backup reinforcing steel (Fig. 5 and 6).

Step 7: Anchorage pockets are then poured using a pre-bagged high-strength portland cement grout (Fig. 7) with appropriate consolidation (Fig. 8).

Step 8: After the grout achieves at least 3000 psi (21 MPa) compressive strength (normally the day after the pour), the strands are restressed using a hydraulic jack calibrated in accordance with PTI M10.2-00[6] (Fig. 9).

Step 9: The strand tails are cut with an oxyacetylene torch or by another approved method. Protective end caps are then installed over the tendon tails and the stressing pockets are patched with a nonshrink grout.

Step 10: Once all of the strands are stressed and anchored at the perimeter of the opening, demolition

Fig. 8: Vibrating repair material for proper consolidation

Fig. 9: Strands are stressed using a monostrand ram

of the remaining concrete in the opening is completed using conventional concrete breakers (Fig. 10). The edge of the opening can be left as a rough, unfinished surface or it can be formed and poured to create a formed edge.

Fig. 10: Excess concrete is removed from the new opening

DESIGNING PT SLABS FOR FUTURE OPENINGS

Sometimes designers take additional steps during the design of a building to provide greater flexibility for future slab penetrations. Various methods can be used to plan for the possibility of future penetrations. Examples of techniques that have been used successfully include maximizing tendon spacing in the slab, marking tendons in the slab, and designing large areas of the slab without PT tendons (sometimes referred to as "knockout panels").

SAFELY AND SUCCESSFULLY CREATING OPENINGS IN PT SLABS

Practical methods exist for creating openings in PT slabs after construction is complete. While the method will vary depending on many factors, there are standard procedures that should be followed when creating such openings. Modifications to existing PT slabs can be made safely and economically when the project team includes an engineer and a specialty contractor experienced in this type of application.

CREDITS

This article is based on a Post-Tensioning Institute publication, "Creating Openings and Penetrations in Unbonded Post-Tensioned Slabs," authored by Don Kline, Kline Engineering & Consulting, LLC. For a more comprehensive discussion of this topic, the reader is encouraged to review this publication and the following references.

REFERENCES

1. PTI TAB.1-06, *Post-Tensioning Manual*, sixth edition, Post-Tensioning Institute, Farmington Hills, MI, 2006, 254 pp.

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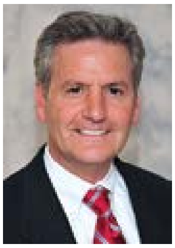

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