A contribution by ACI Committee 134, Concrete Constructability

Constructability of Post-Tensioning Anchors in Shear Walls

by Phil Diekemper, Frank Salzano, and Bruce Suprenant

Many post-tensioned buildings and parking garages are constructed with unbonded single-strand tendons. These tendons typically comprise seven-wire, 0.5 in. (12.7 mm) diameter, Grade 270 [1860]) strands that are greased and sheathed in polymer extrusions and are fitted with encapsulated anchorages.[1,2]

Tendon layout typically consists of concentrated tendons in one direction (banded tendons) and distributed tendons in the other direction (distributed tendons). Tendons are usually anchored at the centroid of the slab thickness using dead-end and stressing-end (live-end) anchors. While the locations of the anchors within the floor area may not be critical to constructability, setting and stressing anchors will affect constructability when the strands terminate near or pass through a structural wall (shear wall). The congested reinforcement in structural walls, especially in buildings constructed in seismic regions, makes the determination of anchor location especially important to constructability.

Figure 1 is a portion of a construction drawing for a post-tensioned slab. While most of the strands terminate with dead-end anchors that can be located outside of the wall section, the plan does indicate that three stressing-end anchors are required to be placed through the structural wall. Figure 2 illustrates how dead-end anchors can be placed near to, but outside of, a wall.

Full-scale experimental earthquake testing[3] of the wall-slab connection with the dead-end anchors placed outside the wall at a distance equal to the slab thickness met performance expectations at maximum drift demands. And the placement of the dead-end anchors (Fig. 2) does not interfere with the wall reinforcement. Thus, the walls could be built ahead of the slabs and slab reinforcement could be anchored to the walls using coupler-bar assemblies with mounting plates that are nailed to the wall formwork (these assemblies are commonly called "form savers" or "dowel substitutes").

Slab reinforcing bars are screwed in the couplers after wall forms are removed. This allows the walls to be formed and placed off the critical path of the slab. It also allows the use of self-climbing wall formwork systems that are used to construct most high-rise buildings. The location of the dead-end anchors minimizes the conflict of post-tensioning reinforcing with the congested structural wall reinforcing.

The stressing-end anchors, however, create a much more complicated issue, as the anchors and associated anchorage zone reinforcement (straight bars and hairpins) may be specified to be installed

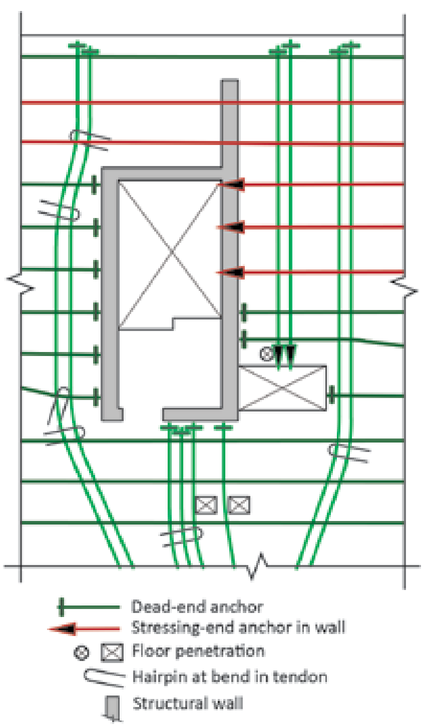

Fig. 1: A schematic tendon layout at a building core. Multiple dead-end anchors are shown near to but outside of the structural walls (in green). However, two tendons (in red) are shown passing through a structural wall extension, and three stressing-end anchors (red arrows) are shown terminating at a wall and thus must be embedded in the wall

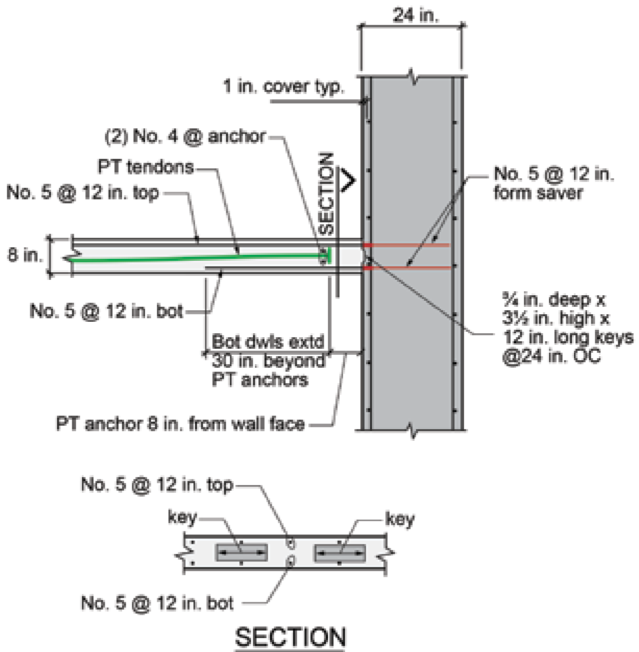

Fig. 2: Schematic of a slab-wall connection with dead-end anchors located outside the structural wall a distance equal to the thickness of the slab (based on Reference 3). Full-scale tests verified that a connection comprising shear keys and dowel substitutes (form savers) achieved a performance objective of 2% interstory drift as required by common building codes (Note: 1 in. = 25 mm)

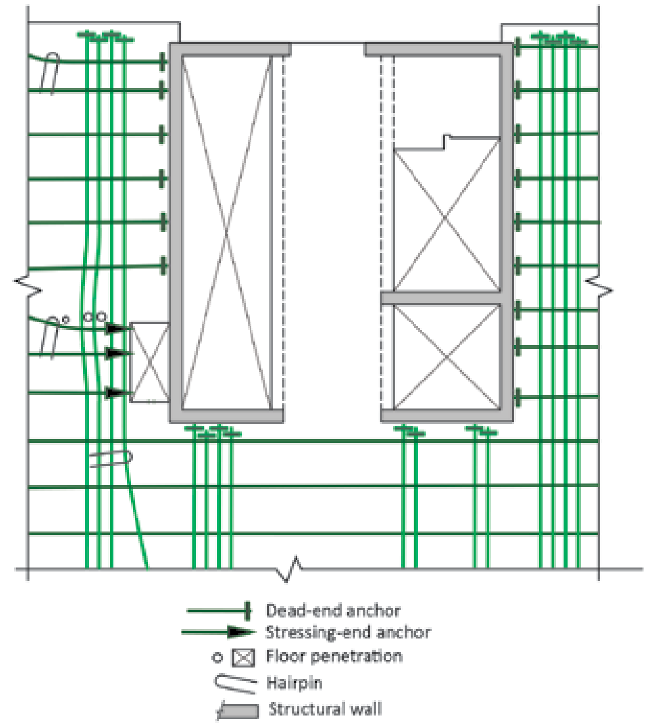

Fig. 3: Stressing-end anchors stopped at a blockout prior to reaching the structural wall

within a congested structural wall. The placement of the anchors within the wall is difficult, and it often requires that the portion of the wall above the slab is not constructed until the slab is in place. This delays the schedule, increases the cost, and creates a difficult quality control issue of installing the anchor and ensuring that the pocket former is perpendicular to the slab edge form.

Avoiding the Structural Wall

There are several possible options to placing the stressing-end anchors within a structural wall. Since there are only three stressing-end anchors for the example shown in Fig. 1, the most logical and cost-effective option would be to create a mini-closure strip (Fig. 3) in the slab at the wall face. Although Fig. 3 shows the stressing-end anchors running into a blockout for a floor penetration, a similar blockout could be reinforced and filled-in at a later date.

Another viable option may be to divert the tendons around the wall (Fig. 4). Sharp bends and transitions should be avoided, and hairpins may be necessary. For an opening this large, it is always desirable to reinforce the top and bottom of the slab at the openings with diagonal bars to control cracking initiated at the corners. Additional structural reinforcement may be necessary around the wall perimeter to distribute any loads.

If there are two structural wall cores, it may be possible to place the stressing-end anchors within a closure strip constructed between the walls. While this may be a reasonable solution when the walls are widely spaced and a closure strip is required to avoid excessive friction losses in the tendons, it is not the ideal solution. Control strips are typically left for 30 days—this may delay the construction schedule and create a potential safety hazard.

Another option is to construct a blockout in the wall at the slab (Fig. 5). Although this allows the wall to be constructed independently of the slab, the blockout is usually very difficult to form, especially for structural walls in high-seismic regions.

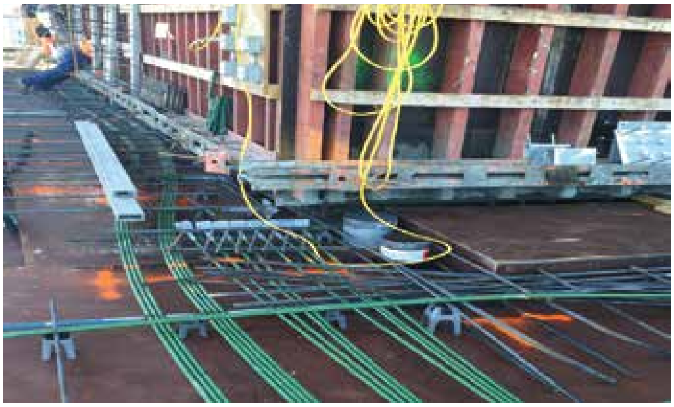

Fig. 4: Tendons routed outside of structural walls. This may be possible on short walls but is more difficult to achieve with longer walls

Figure 6 illustrates dead-end anchors running through the wall and along inside the interior of the wall. If this condition is shown on the construction documents, a Request for Information (RFI) should be sent to ask that the dead-end anchors be relocated to start at the outside of the wall and that the post-tensioning strand located within the wall be relocated to be in the slab outside of the wall. The design of the core landing slab could also be changed. The short-span slab does not require post-tensioning, and the inclusion of post-tensioning forces the contractor to place core slab in conjunction with the main floor slab. This limits the core formwork options and may slow the project schedule. Oftentimes, core slabs are placed after the core wall formwork trailing work platforms have moved above the floor elevation

Fig. 5: Blockout in structural wall for stressing-end anchors. Backup bars are not shown *(photo courtesy of James McHugh Construction Co.)*

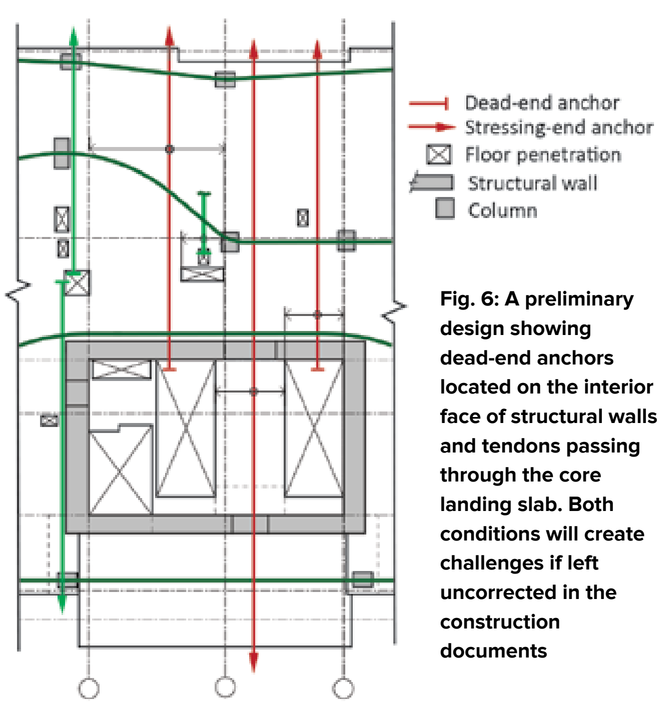

Fig. 6: A preliminary design showing dead-end anchors located on the interior face of structural walls and tendons passing through the core landing slab. Both conditions will create challenges if left uncorrected in the construction documents

(the core shown in Fig. 3 will accommodate this option). As mentioned previously, the slabs can be anchored to the wall via dowel bar substitutes. These suggested changes would improve the schedule, cost, and quality of the project.

Engineers should consider constructability issues when locating dead-end and stressing-end anchors, as those choices most likely influence the cost, schedule, and quality control for the project. When possible, consult an experienced concrete contractor for cost-effective options.

References

1. Joint ACI-ASCE Committee 423, "Specification for Unbonded Single-Strand Tendon Materials (ACI 423.7-14)," American Concrete Institute, Farmington Hills, MI, 2014, 8 pp.

2. ASTM A416/A416M, "Standard Specification for Low-Relaxation, Seven-Wire Steel Strand for Prestressed Concrete," ASTM International, West Conshohocken, PA.

3. Klemencic, R.; Fry, J.A.; Hurtado, G.; and Moehle, J.P., "Performance of Post-Tensioned Slab-Core Wall Connections," *PTI Journal*, V. 4, No. 3, Dec. 2006, pp. 7-23.

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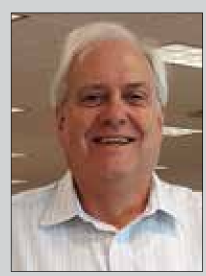
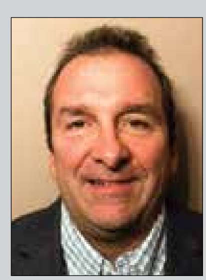


Phil Diekemper is Senior Vice President North Operations, CECO Concrete Construction. Since starting his career with Ceco as a laborer, he has gained experience in about every position within the company. Among his many volunteer activities, he serves on the Advisory Board of the Safety and Risk Management Council of the American Society of Concrete Contractors (ASCC).



ACI member **Frank Salzano** is Director of Quality Control, CECO Concrete Construction. He is a member of Joint ACI-ASCC Committee 117, Tolerances. Salzano received his BS in civil engineering and MS in construction management from Virginia Tech, Blacksburg, VA. He is a licensed professional engineer in Virginia and other jurisdictions.

Bruce Suprenant, FACI, is Technical Director, American Society of Concrete Contractors. He is a member of the ACI Technical Activities Committee and numerous other ACI committees. His honors include the 2013 ACI Certification Award, the 2010 ACI Roger H. Corbetta Concrete Constructor Award, and the 2010 ACI Construction Award.