Cutting Prestressed Concrete Framing

Design and Construction Considerations

By Michael F. Hughes, P.E., S.E., and Sal A. Capobianco, P.E.

Existing owners often consider repositioning options for their buildings to serve an ever-evolving tenant market, accommodate new building uses, improve pedestrian circulation and accessibility, increase rentable tenant space, and more. Often, these buildings are served by an abutting above-grade parking structure, which can prevent horizontal expansion unless portions of the garage are removed to accommodate the expansion.

Many parking garages are constructed of precast, prestressed concrete (PC) framing members. PC has the favorable characteristics of structural steel framing, such as allowing for "stick-built" construction and using long, shallow spans. PC also has significantly more durability than conventional mild-reinforced concrete, since it is cast in a controlled environment. Unlike structural steel and mild-reinforced concrete, PC framing is under constant internal stress from the prestressing strands. Partially removing or modifying PC framing elements can appear to be a complicated design and construction challenge, for which there is little published technical guidance as compared to the other traditional building materials that are not under constant internal prestressing.

This article examines the structural considerations of modifying existing PC floor elements and provides a case study where these methods were used successfully. The focus is on simply supported tee beams with fully bonded strands. It is important to note that projects and structures are different, and additional considerations may be applicable depending on the specific project.

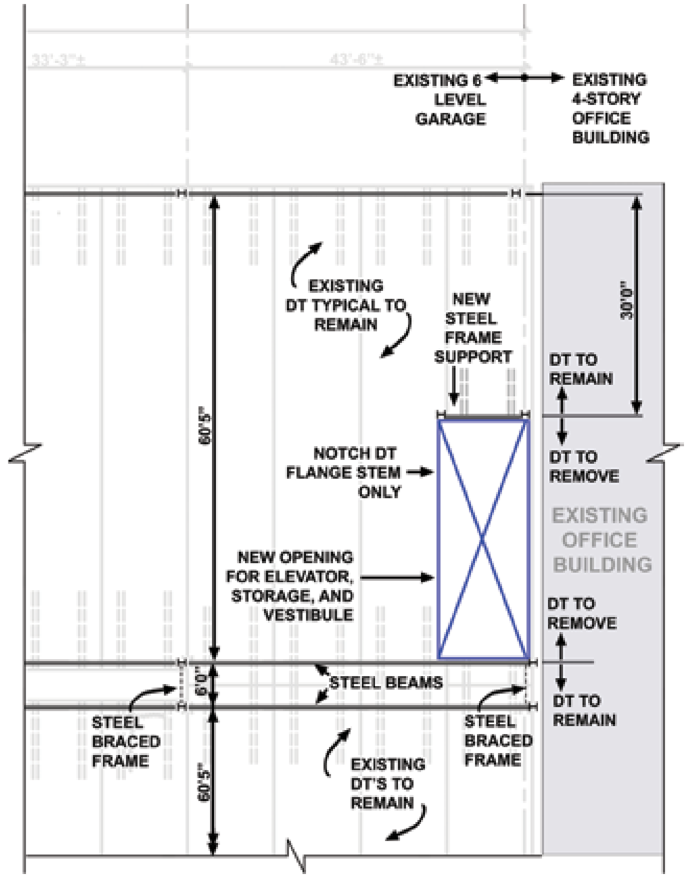

Figure 1. Plan view of the opening in the existing parking garage.

Design Considerations

Internal prestressing is achieved through the bond between the prestressing strands and the concrete. The prestressing strands are located and stressed to create internal flexural stresses in the member that counteract the flexural stresses from externally applied loads. Parking structures commonly use double-tee beams as floor members. In relatively new parking garages, strands are typically straight, whereas older designs utilized a draped strand that varies in height along the length of the beam. If the location and quantity of the strands are unknown, ground-penetrating radar (GPR) can be used to locate the strands and other embedded reinforcement necessary to evaluate the existing PC member.

When an existing PC member is shortened, the flexural stresses in the member will change. Flexural stresses from applied loads are lower for the shorter span, assuming the design loads do not change. For PC, the flexural stresses from the prestressing force are not dependent on span length and will not change if the span is reduced. In general, the total stresses under the full design load will be lower for the shortened span. However, in the unloaded condition (i.e., no live load), flexural stresses from the prestressing can overstress the member.

The flexural stresses in the loaded and unloaded cases must be checked against code-prescribed allowable stresses for the new span length. Stresses can be calculated using standard PC design methods. For PC members with draped strands, flexural stresses from prestressing will be asymmetric; therefore, checks are required at multiple points along the member's length. Adding dead load (i.e., ballast) could reduce the flexural stresses from the prestressing.

PC beams typically contain added shear reinforcement near supports, but not always along the entire length of the beam. When the beam is shortened, the new supported end may have inadequate or no shear reinforcement. Although the shorter span length will reduce the demand shear forces, the shear stress must be checked at the new cut end. ACI-318 requires the concrete shear capacity to be at least twice the demand to have a section without shear reinforcement. The additional shear strength provided by the prestressing can be included. Shear or flexural reinforcement, such as carbon fiber, can be added externally to strengthen the member. Since carbon fiber does not provide the fire resistance required for many structures, an intumescent paint or other fireproofing material may need to be applied over the carbon fiber material.

PC beams are designed to have similar cambers between the adjacent members. Differential cambers create tripping hazards and obstruct drainage. Adjacent PC beams of different lengths are designed for minimal differential camber by adjusting the bond lengths of the prestressing strands prior to concrete placement, but it is impractical to modify the bond length of the strand after concrete placement. When an existing PC member is shortened, the remaining portion of the member will deflect upward due to the reduced external load and unchanged internal prestressing force. The approximate amount of anticipated differential camber should be checked against serviceability and other project-specific criteria. A maximum of a ¼-inch vertical differential is typically allowed by the American Disabilities Act (ADA) for pedestrian walkways. If the expected camber exceeds ¼ inch, the surface can be ground down, or additional dead load could be added.

The perimeters of double-tee (DT) beams typically contain diaphragm reinforcement necessary to transfer the in-plane wind and seismic loads to the building's lateral-load-resisting system (LLRS). Typically, chord reinforcement is located at each end, and collector reinforcement is present where the PC element connects to the LLRS. Diaphragm reinforcement bars are usually spaced closely together and located approximately 1 foot from the end of the member. It is common for three to five bars to be provided for the collector or chord reinforcement in moderate seismic areas. When a portion of the PC framing is removed, this reinforcement is lost and needs to be substituted. Additional framing may be required to transfer loads into the LLRS or reinforce the PC framing chords if the diaphragm load path is interrupted.

Construction Considerations

Partially demolishing PC is an uncommon demolition task, and a pre-construction meeting with the construction team should cover the special circumstances of partially removing PC. In addition to typical logistic items covered at these meetings, the expected behavior of the PC, cutting procedures, items to monitor, demolition sequence (start at the uppermost level and work down), and identifying stop points in the work to check for distress must be discussed. It is also important to discuss potential behavior for which the Contractor should notify the Engineer.

Material stockpiling, equipment that will be used, or any other atypical live loads, such as vehicle barriers, skid steers, trucks, etc., also need to be coordinated. These loads can exceed the design load of the existing framing, and the framing may need to be checked for these loads. A preconstruction inspection should be performed and compared against observations during construction to identify any new distress.

New supplemental framing to support the cut end of the PC member will likely need to be installed before demolition. The portion of the member to be removed will likely need to be shored as well. This shoring can also be configured to act as a debris shield for the demolition work. Debris shielding should be designed to support the weight of the demolished materials plus appropriate construction live loads. Shoring should extend down to grade if possible; however, it may be possible to terminate shoring if there is adequate capacity for the shoring loads at a lower level.

It may be possible to use a crane to remove the portion of the member to be demolished. This option might eliminate the need for shoring and noisy demolition work near an existing building. However, there are significant rigging and logistical challenges that make this option impractical for most applications. In other words, extreme care must be taken when cranes are employed for partial demolition of PC.

When the existing member is cut, it will camber upward or move differentially from the adjacent existing construction. Therefore, the existing member must be disconnected from adjacent structural elements, including beam-to-beam connections and chord and diaphragm splices, to avoid damaging the connections or adjacent elements. These elements will need to be reattached after the work is complete. Nonstructural elements, such as partition walls, should be temporarily disconnected and modified if the expected amount of upward movement exceeds their deformation capacity.

The PC to be demolished will likely be removed in sections. The size of each section will depend on the construction logistics. Saw cutting should start at the joint between the section to remain and the section to be removed so that the remaining portion is not affected by the segmental demolition of the adjacent PC. Saw cutting should begin in the tension zone, to prevent binding the saw blade. After cutting the joint between the portion to remain and the portion to be demolished, it is advantageous to remove mild-reinforced portions of the PC first, such as the flanges of the tee beam. This will reduce the dead load and increase upward camber, further reducing the potential for binding the saw blade.

During saw cutting, some "popping" noises may be heard as the strands are cut. The Contractor should inform the Engineer if this occurs. Frequent popping sounds may indicate that the strands are debonding, which will require immediate review. Horizontal concrete cracking along the strand typically indicates strand debonding. It is essential to look for any unexpected cracking in the PC that is to remain, such as shear cracking at the support, horizontal cracking along the strand, or tension cracking at midspan. Work should be stopped until unexpected cracking issue or consistent strand popping are understood and resolved.

Case Study

In 2018, the Owner of a four-story office building was exploring opportunities with a potential new tenant; however, the existing building elevator configuration and capacity did not suit the tenant's needs. Adding another elevator inside the building was not possible as it would be too disruptive, so the Project Team explored adding an exterior elevator. The Richmond Group (TRG) was the Design-Builder for the project, and Simpson Gumpertz & Heger Inc. (SGH) was the Structural Engineer of Record.

Three sides of the building abutted a street, a parking lot, and conservation land. The fourth side of the building abutted an existing, six-level parking garage. The project team decided to "notch" a portion of the existing parking garage and install a new building elevator in the garage to service the building. The elevator required a new vestibule at each floor, and new storage rooms were added at each floor above the first-floor machine room, which increased the rentable area on the second, third, and fourth floors. To complicate matters, the floors of the garage and the office building did not align on the upper levels. The elevator would service the building levels only and would only align with the garage on the ground floor.

The existing parking garage consisted of a steel-framed superstructure with braced frames in the short direction and moment frames in the long direction.

Figure 2. Steel support framing installed prior to demolition. Shoring towers for the portion of the PC framing to be demolished can be seen in the background.

Figure 3. Supplemental horizontal steel bracing to the restore diaphragm connection to LLRS.

Figure 4. Top 3 levels of PC DT framing demolition immediately after removal at Level 4. Courtesy of The Richmond Group.

PC DT beams spanned approximately 60 feet between steel girders to form the parking deck. The DTs were approximately 11 feet wide and 30 inches deep. The new elevator hoistway required an opening approximately 14 feet by 30 feet to provide new vestibule and storage room floors that aligned with the office levels. This cut required completely removing 30 feet of the DT closest to the building and notching the flange of the next adjacent DT up to the stem. *Figure 1 (page 8)* shows the plan layout of the new garage opening. The remaining portion of the DTs would still be used for garage parking.

Structural drawings were not available, and the reinforcement and strand profile of the DTs was unknown. SGH used GPR to determine the location and quantity of the strands and their profiles. There were seven straight profile strands in the DT stem. GPR also showed three collector reinforcement bars along the long edge of the DT flange that connected to a braced frame and three-chord reinforcement bars along the short edge of the DT flange. Test pits showed that the existing garage was founded on shallow spread footings.

The portion of DT to remain was supported on a new steel frame (*Figure 2*). The new steel columns were founded on new shallow foundations and laterally attached to the DT at each level for frame stability. The bottom of the new foundations was set at the same elevation as the existing garage and building foundations to avoid surcharging those foundations. The existing diaphragm connection of the DT to the braced frame would also be removed as part of the demolition; therefore, new horizontal steel bracing was added to connect the remaining diaphragm to the LLRS (*Figure 3*).

The strand diameters were initially estimated based on the as-designed DT length and code-required live loads and were confirmed via a small opening at the end of the DT stem at the start of construction. The analysis showed that the flexural stresses in the DT to remain were within ACI limits in the loaded and unloaded conditions. The additional upward camber increase was estimated to be only ⅛ inch; therefore, differential camber was within tolerance.

Shear strength at the cut location was a significant consideration. The DT did not contain any shear reinforcement at the cut location. The concrete strength and compression from the prestressing provided the required shear strength. It was determined that the shear strength of the existing portion of DT that remained was at least twice the required shear demand. Therefore, additional shear reinforcement was not required.

TRG installed the steel frame by cutting localized openings in the flanges for the columns to pass through and then installing the beams under the DT stems before removing the DTs. The full portion of the DT was removed in sections at night, and the garage remained operational during the day. The DT was shored using standard shoring frames, aluminum beams, and plywood to create a combined shoring platform and debris shield at each level, and was supported on grade. Demolition started at Level 6 (roof) and proceeded downward. Five levels of DTs were cut and removed. *Figure 4* shows the demolition progress at Level 4. The Contractor reported that they did not hear any popping sounds consistent with strand slip and no new distress was observed. Once demolition began, it took the TRG approximately three days to remove the portion of the DT at each level. The demolition work went smoothly and was considered a success by all parties.

Conclusion

Projects requiring modifications to existing PC framing have a unique set of design and construction challenges that differ from those of traditional building materials. Consideration must be given to changes in flexural stresses, shear resistance, camber, and relative displacements. Demolition and construction means and methods require close coordination and communication between the design and construction teams to ensure that all parties understand the unique behavior of PC. In conclusion, existing PC members can be successfully modified in place by carefully reviewing and addressing all of the unique design and construction challenges associated with the work.▪

Michael F. Hughes is a Senior Project Manager at Simpson Gumpertz & Heger's office located in Waltham, MA. (mfhughes@sgh.com)

Sal A. Capobianco is a Senior Principal at Simpson Gumpertz & Heger's office located in Waltham, MA. (sacapobianco@sgh.com)