Fire Damaged Post Tensioned Slabs

Kearney Plaza Today: Post-tensioned slab Courtyard

By Douglas Sarkkinen, P.E., S.E.

The $19 million Kearney Plaza is a 5-story multi-family residential, retail and parking facility in the Pearl District just north of downtown Portland, Oregon. As is typical for many of the 5-story or less mixed-use buildings, residential units and most of the retail spaces are constructed using wood framing. The wood framing is on a 1-story concrete podium consisting of a 13-inch thick post-tensioned concrete slab, 10-inch thick concrete perimeter walls, and concrete columns on spread footings. Covering 40,000 square feet, the post-tensioned concrete slab serves as the fire separation between parking below and wood-framed residential above, as well as supporting the loads of the 5-story apartments, the retail and a plaza area containing landscaping and a courtyard. In keeping with the building overall fire safety, concrete walls also surround the parking ramp, which had a 12-inch post-tensioned concrete slab cover.

In the early hours of August 19, 1999, a four-alarm fire raged through the Plaza while it was still under construction. Starting at approximately 4 A.M. and burning all day, the fire turned the wood frame into a heap of ash just three months shy of Kearney Plaza's originally scheduled opening. At one point, heat was so intense that thermal expansion of windows in the adjacent Riverstone Condominium created so much noise residents were forced to evacuate. Although the fire was nearly extinguished by the end of the first day, it wasn't until the third day that fire investigators, along with the Contractor, began to clear debris on the concrete deck to search for the cause.

Kramer Gehlen and Associates, Inc. (KGA), the Structural Engineer of Record for the original building design, was notified immediately of the catastrophic fire. Although present at the site shortly thereafter, KGA could not gain access to the structure because of hazards presented by smoldering contents on the slab and life safety concerns from precariously hanging debris. In fact, for first week immediately following the fire, investigators took control of the site and allowed no one access without proper authorization. Shortly after the fire, the Owner, Contractor and their insurance company decided to re-build as quickly as possible following debris removal. However, fire investigation had to be complete before any type of clean up or restoration could begin.

KGA was retained to help guide the Contractor during cleanup and demolition, assess the structural integrity of the components remaining after the fire and provide engineered options for repair of structural elements that, although damaged, might be salvageable. With the majority of the upper floors an ash heap on top of the post-tensioned plaza slab, the wood framing was clearly an economic loss. Similarly, the structural steel framing located above the plaza level, within the retail area, was effectively destroyed and needed replacement. There were some concrete walls above the plaza level at the retail areas that remained standing, although they appeared severely damaged. The post-tensioned plaza slab could not be seen, since it was buried under several feet of debris. Basement access was not allowed until investigators had cleared the area and determined there were no collapse hazards present.

Fire investigators required their presence during initial debris removal to observe and inspect all aspects of the scene. They soon focused on the southwest corner, since evidence was developing that was the probable location of the start of the fire.

To expedite debris removal, the Contractor asked to place large excavation equipment on the plaza slab. Evaluating whether the potentially fire-damaged post-tensioned concrete slab had sufficient capacity to support large equipment proved to be one of the first challenges required for reconstruction of this building. To adequately assess damage, KGA needed to visually inspect the slab; however, the Contractor needed to get equipment on the slab to clear debris so visual assessment could occur.

Kearney Plaza Today: Retail

A systematic method was developed where small portions of the slab immediately in front of the excavation equipment were cleared, allowing structural engineers to verify the extent of damage for that portion of slab before proceeding. In addition, basement access was eventually granted. No signs of distortion, sagging, or adverse cracking on the slab underside were evident, except for some localized areas around stair and elevator penetrations. Additionally, concrete cores were taken at areas that spalled and appeared damaged to determine if slab delamination had occurred. The initial cores were found to be sound and intact. Based on this evidence, the Contractor was given approval to use equipment weighing up to 25 kips. Larger equipment or trucks would require shoring.

After removal of a majority of debris, investigators determined arson was the most probable cause. The investigators collected as much evidence as possible, eventually returning site authority to the Contractor. With most debris removed, the most difficult aspect of reconstruction was to determine how much structure could be saved and how much needed removal and replacement. This issue had significant ramifications in terms of reconstruction time and costs.

The first assessment dealt with concrete elements above the plaza level, including exterior walls at the retail area, and the walls and post-tensioned concrete slab over the parking ramp. Several of the walls were specified to be architecturally exposed concrete and, though they appeared structurally sound, they could not be repaired to achieve the necessary architectural aesthetics. Additionally, walls along the parking garage ramp experienced significant spalling. It was believed these walls could be repaired by adding shotcrete to the wall surface, but estimates indicated repair costs would be nearly as much as the costs of removal and replacement. Therefore, it was determined that all concrete elements remaining above the plaza level would be demolished and rebuilt.

The post-tensioned plaza slab was the remaining critical element that could have been irreparably damaged. Because of potential impact to scheduling and costs, there was a strong desire from both the Owner and Contractor to save the slab. The main concern was determining the temperature level experienced during a fire that burned all day. At extremely high temperatures, concrete can be damaged and steel reinforcing and post-tensioning tendons can experience strength and stiffness loss. The table below indicates damage that might be expected as structural materials are exposed to the respective temperatures. This table is a compilation of information from Construction Technologies Laboratory (CTL), ACI, miscellaneous articles on fire damage and some testing by a local testing agency.

Spalling occurred throughout the top surface of the plaza slab, with some areas being heavily damaged while in other areas the damage was sparse. It was believed that contact between the cold water used to extinguish the fire and the heated slab contributed to the concrete spalling. The depth of a majority of spalling was in the ½-inch to ¾-inch range. Since the majority of tendons in the slab had a minimum 2 inches of cover, it was determined the spalling probably did not compromise slab structural integrity. Spalling was repaired by removing loose concrete and patching with a cementitous leveling compound.

As shown in *Table 1*, spalling of dense concrete can occur at temperatures in the 200 to 300 degree Fahrenheit range. The concrete specified for this project was 5,000 psi strength, normal weight concrete with a target 0.45 water-cement ratio. Consequently, because of the extent of concrete spalling, it is clear that temperatures on the slab likely exceeded 300 degree Fahrenheit. However, to extrapolate the type of structural damage or strength loss that may have occurred, a more accurate temperature assessment was desired. Thus, several other items were considered to determine possible temperature levels:

- Discussions with fire investigators,
- Concrete core samples taken and observed for discoloration,
- At 6 locations the concrete was chipped down to expose PT tendons, and
- Steel deformed bars were exposed at the same 6 locations.

In review of all tests performed, experience of fire investigators and the extent of slab damage observed, the temperature attained was likely in the 500 degree Fahrenheit range. This conclusion was based on:

Discussions with Fire Investigators indicating that, although the fire was catastrophic, the majority of heat and energy went straight up as flames reached over 100 feet. The fire was described as being similar to a furnace, pulling cool air low into the fire along the slab and feeding from the base. This effect probably did not create intense heat at the slab surface. Subsequently however, as the fire progressed and the wood-framed components continued to burn, the building collapsed within itself and created 2 to 3 foot layers of charcoal on top of the slab. This possibly "baked" the slab;

TEMPERATURE EFFECT ON POST-TENSIONED SLABS	
Temperature	Observed Damage
200 – 300°F	Spalling of dense concrete.
400°F	Melting of the plastic sheathing around tendons.
600°F	Relaxation of post-tensioning strands begins. Discoloration of concrete.
1,200°F	Yielding of mild steel reinforcing.

Table 1



Exposed Post-tensioning tendons

however, investigators suggested this was likely at temperatures in the hundreds, not thousands, of degrees Fahrenheit.

Concrete Core Samples were taken at areas with significant spalling and were sent to Construction Technologies Laboratory (CTL) for petrographic analysis. These core samples showed no signs of discoloration. The petrographic analysis identified a surficial layer of concrete affected by higher temperatures, as evidenced by the appearance of a slight softening of cement paste. This affected layer, however, was only 0.02 to 0.04 inches thick. CTL also indicated that, for these cores, the concrete surface layer temperature did not remain high long enough for desiccation microcracks to form. CTL concluded that petrographic findings suggested the concrete layer was subjected to temperatures of approximately 400 to 550 degrees Fahrenheit.

Post-tensioning Tendons and Deformed Bar Reinforcement were exposed and investigated at several locations. In only one of the 6 cases of exposed tendons, the protective plastic sheathing exhibited signs of melting but the strands and grease appeared to be still intact. The exposed reinforcing bars did not show signs of heat scarring, and there was no indication of concrete delaminating or spalling around the deformed bars.

Based on the above, it was determined the post-tensioned slab did not lose structural capacity except for a few isolated damaged areas by stair and elevator openings. These were subsequently repaired, along with other portions of the structure; however, the majority of the plaza slab remained intact without repair and functions satisfactorily today.

Along with investigation and repair of slab concrete portions, there was a substantial number of steel anchor bolts and hold-down anchors protruding through the slab surface. A large percentage of these were bent or damaged during the fire or subsequent cleanup operations. All bent or damaged anchor bolts and all hold-down anchors were load tested in place, with some requiring repair.

In summary, investigation into the extent of fire damage and remaining structural integrity in the post-tensioned structural slab focused primarily on identifying temperature levels experienced. With known behavior of structural materials, potential damage to concrete elements may be inferred. Even though this post-tensioned concrete slab experienced a catastrophic fire, and concrete spalling was prevalent throughout, there was enough cover and redundancy in the system to maintain structural integrity. Repair was required at localized areas; however, saving the structural slab proved to be critical to project completion. The Contractor indicated that, by reusing the podium slab, clean-up and rebuilding costs were slightly below the Owner's Builder's Risk limits. Since policy limits were not exceeded, there was no reason to identify who was responsible for the fire, avoiding lengthy and costly litigation. This allowed the Contractor to finish work without trying to recover expenses.▪

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Loss of embedded anchors

Photographs of the fire damage are courtesy of the contractor.