Shrinkage-Compensating Concrete in Post-Tensioned Buildings

A Four-Building Survey – Part One

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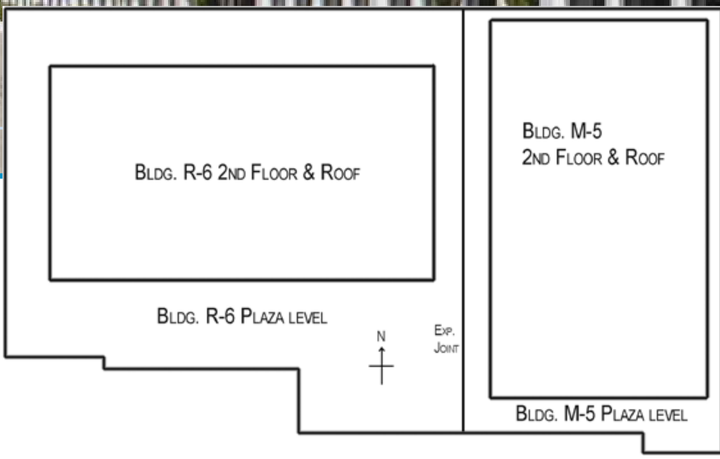

Buildings M5 and R6 (plan view). These two buildings required elevated concrete decks with no control joints or pour strips. Shrinkage-compensating concrete was successfully used to cast all floor members. The buildings continue to perform well more than 40 years later. Courtesy of CTS Cement Mfg.

South Elevation Building R6 – Looking Down 439-foot Length at Plaza Level. Courtesy of Phillip Yee of Northrop-Grumman.

Restraint to shortening (RTS) is a major concern for designers of post-tensioned concrete buildings. It can cause unsightly cracking in floor systems and restraining elements (columns and walls). Although the total volume change in post-tensioned concrete buildings is not very different than it is in non-prestressed buildings (shrinkage is the biggest contributor in both), post-tensioned buildings shorten differently than non-prestressed buildings and present unique RTS problems.

In non-prestressed buildings, the total concrete volume change consists of the sum of many closely spaced cracks that develop between the ends of the floor system, each with relatively small width. The ends stay roughly in the same position in which they were originally placed. Restraint forces are minimal because the many distributed cracks relieve stress in the floor system and the connected columns and walls.

In a post-tensioned building, however, the prestressing force fully or partially closes cracks which develop in the floor system, and the ends tend to move inwards. This movement is resisted by restraining members, and can generate large forces that produce severe cracking in the floor system and in the walls and columns. Typical solutions to mitigate RTS cracking have included joinery details (expansion joints, pour strips and slip joints) and added non-prestressed reinforcement to distribute cracking. These measures, while effective, are expensive, cumbersome, and can impact resource usage and construction time.

There is another proven method for solving RTS problems that has been used for over 40 years, yet it is not well known and deserves wider recognition. Shrinkage-compensating concrete has been successfully used to construct large, jointless elevated slabs in post-tensioned concrete structures since the 1960s. Made with ASTM C845 Type K cement, the concrete expands slightly during the first seven days of curing, after which it undergoes a normal amount of drying shrinkage, for net volume change closely approaching zero.

For the short period of time after placement when shrinkage-compensating concrete expands, growth of the floor system is restrained by connected members. Restraint forces are minimal because the stiffness of the restraining members is not fully developed. After expansion, normal drying shrinkage begins and restraint forces *decrease* with time, approaching zero as the magnitude of the shrinkage approaches the initial expansion. Long-term volume change is greatly reduced, permitting the elimination of, or greatly increased spacing between, expansion joints and pour strips.

This article, in two parts, presents case studies of four projects on which shrinkage-compensating concrete was used. Two of these projects were built more than 40 years ago; one has been in service for 12 years, and one is new, completed just 19 months before this writing. On two of the projects (the newest and one of the oldest) measurements of volume change versus time were made. In this first part, the two oldest buildings are described. The other two buildings surveyed will be presented in a second article to be published in a future issue of STRUCTURE®. These four projects demonstrate the effective use of shrinkage-compensating concrete to mitigate RTS cracking in post-tensioned concrete buildings.

Santa Monica Parking Structure #2

In the late 1960s, the city of Santa Monica, CA, built six municipal parking structures. All were designed by the structural engineering firm T.Y. Lin and Associates, Van Nuys, CA, where I was employed and did some structural work (seismic load analysis) on several of them, including Structure #2 discussed here.

Each building was designed for eight elevated levels; four to be built initially, with the capacity for an additional four levels to be added as the need for parking increased. Floors were framed with monolithic cast-in-place post-tensioned lightweight concrete using one-way slabs spanning to clearspan beams (*Figure 1*). Plan dimensions are approximately 150 feet (three beam spans) by 200 feet (9 slab spans.) One slab construction joint was used, running in the short direction at roughly the third point of the long direction (some of the upper floors used two construction joints). There were no pour strips.

Of particular note is Structure #2, located at 1235 2nd Street. The original four levels (370 cars capacity) were built in 1968, with Type K shrinkage-compensating concrete in the floor systems. Around 1980, an additional four levels were added using conventional portland cement concrete. A series of pins were set into the original deck so that measurements of strain in the slab concrete could be made. These measurements were made at the following points in time:

- Prior to post-tensioning (first seven days after placing concrete)
- During and immediately after slab post-tensioning (seventh and eighth day after placing concrete)
- At intervals for the subsequent five years

The total shortening strain measured five years after concrete placement was 0.00034 in./in. In the same study, total shortening strain in a similarly framed industrial building in Pasadena, CA, built using lightweight concrete with Type II portland cement, was measured at 0.00112 in./in., more than three times higher.

I inspected the entire floor area of Structure #2 in November, 2009, 41 years after completion of the lower four floors. I carefully observed the areas most susceptible to cracking: the four corners, two with stair/elevator shafts and two without, the ends of the central longitudinal concrete shearwalls, and the areas around the girder framing at each turn-around aisle.

I measured a total of 80 lineal feet of cracks in the lower four floors built with shrinkage-compensating concrete. All of this cracking was on the first elevated slab in the northeast and southwest corners of the building, near the two elevator/stair shafts. The orientation of cracking was consistent with RTS, aggravated not only by the shafts, but by the proximity of a length of basement wall in each location. The largest crack width I measured was 3⁄32 inch and the longest crack length was about 18 feet. The cracks were visible at the top and bottom of the slab (when both were accessible), and I saw no evidence of efflorescence at the bottom of any crack, suggesting there was no significant moisture penetration. The southeast and northwest corners of the first elevated slab, lacking shafts and basement wall conditions, were crack free.

I saw no cracking in any structural member (slab, beam, girder, concrete shearwall, masonry shearwall or column) anywhere else in the lower four floors. I observed some minor spalling between the edge of the slab and the masonry wall at the northeast stairshaft at a few levels. Most experienced observers would rate the condition of these lower floors as excellent, with less than 100 lineal feet of cracking in about 120,000 square feet of elevated deck. This is particularly impressive considering the structure has been extensively loaded and unloaded with automobiles on a daily basis for over 40 years. It has also experienced two major earthquakes of Richter 6.0 or larger (San Fernando in 1971 and Northridge in 1994).

Figure 1: Beam and Slab Framing (4th Level).

Santa Monica Parking Structure #2.

The upper four floors, added at a later date without the use of shrinkage-compensating concrete, contain some widely distributed random cracks, most of them visible on the top level. Of particular interest is a very noticeable crack running in the north-south direction on the top (9th) level at the north end of the building, in the exterior slab span along the grid line separating the west and center aisles. This crack is about 15 feet long, visible at the top and bottom of the slab, measuring 1⁄16 inch wide at the top and hairline at the bottom. A similar crack is visible in the asymmetrical location near the southeast corner, but smaller with a measured width of 1⁄32 inch at the top of the slab. I did not observe this crack at the same location on any other floor. The crack at the top level may have been aggravated by temperature effects since it is fully exposed to the environment, but the presence of this crack on a floor built with conventional concrete, and its absence on lower floors built with shrinkage-compensating concrete with more severe RTS conditions, suggests that shrinkage-compensating concrete made the difference.

The plan dimensions and restraint conditions of this building are modest. The slab-to-wall joinery details were typical for the time and were the same as those normally used in buildings with conventional concrete. Nonetheless, the unusually good condition of the lower four floors of this building can be, in my opinion, attributed to the use of shrinkage-compensating concrete.

TRW Buildings M5 and R6, Redondo Beach, California

In 1968, the TRW Corporation (now Northrop-Grumman) added two new buildings to its complex in Redondo Beach, CA. One was for manufacturing (called M5), the other for research (R6). Atlas Prestressing Corp. in Southern California, my employer at the time, provided consulting services for the design of the post-tensioned floor system to the Architect/Engineer, Albert C. Martin & Associates (now A.C. Martin Partners), and furnished and installed the post-tensioning tendons and non-prestressed reinforcing steel in both buildings for the general contractor, Swinerton & Walberg. I was personally involved in both the design and construction of these buildings.

Each building has three stories, a large first floor plaza level, a second floor, and a roof. The second floors and roofs of the buildings are identical in plan dimension, each 199 feet x 363 feet. The first floors of each building are adjacent, separated by an expansion joint, and orthogonal dimensions are very large: for M5, 422 feet x 243 feet; for R6, 439 x 407 feet. All construction was cast-in-place post-tensioned concrete with unbonded tendons. Column spacing was large, with typical bay sizes of 40 feet x 64 feet. Floor system framing was a one-way slab (shallow

Building M5, southeast corner showing dramatic cantilevered post-tensioned beams at Plaza Level. Courtesy of Phillip Yee of Northrop-Grumman.

pan joists in R6 for extra stiffness) spanning between beams located on and midway between column lines. The intermediate beam was supported by a girder spanning between columns. Seismic framing for both buildings was provided by moment-resistant beam-column frames in both directions.

Aside from the large plan dimensions, these buildings presented major challenges for the designers in the mitigation of RTS cracking:

- Other than the joint separating the two Plaza Levels, no other expansion joints were permitted by the owner due to the highly sensitive precision research and manufacturing equipment that would be housed in both buildings.
- Temporary separation joints, such as pour strips, were ruled out by the contractor because of the difficulty of passing them through heavily reinforced beams and girders.
- Axial prestress compression was high, slightly above 300 psi in each direction, thus aggravating the effects of axial shortening.
- Lightweight concrete was used in the floor systems, further increasing the effects of axial shortening and creep because of the reduced modulus of elasticity.
- Columns below the Plaza level were large (37 inches square with 16-#14 vertical bars) providing significant restraint to floor shortening.

Considering these difficult conditions, a decision was made by the designers to use Type K shrinkage-compensating concrete for *all* floor members in both buildings.

The use of shrinkage-compensating concrete was highly successful in the TRW buildings. Recently, more than forty years after construction, I had the opportunity to observe the buildings, in the presence of Northrop-Grumman facilities personnel. The structural condition of the observable portions of the floor system and columns was excellent, virtually crack-free after four decades of continuous service. Northrop-Grumman facilities personnel (Jimmy Guerrero, P.E., Facilities Project Manager, and Phillip Yee, Facilities Risk Manager), who have worked onsite at this facility for years, report that the structural performance of the buildings has been excellent and they have required no unusual maintenance or repairs over their entire service lives.

Conclusion

RTS is one of the two biggest problems faced by the post-tensioning industry (the other being tendon corrosion). Looking back over the growth of post-tensioned concrete for 5 decades, and the early efforts to solve the shortening problems, it seems that the use of shrinkage-compensating concrete could have made the solution to the RTS problem easier.

The two buildings discussed in this article clearly demonstrate the utility of shrinkage-compensating concrete to solve RTS problems. Their long-term performance is testimony to the durability of this technology. They show (as we shall also see in the second part of this article) that when properly mixed, placed, finished and cured, it can substantially eliminate pour strips, and with due consideration of temperature effects, can realistically increase the maximum length between expansion joints to approximately 500 feet, with equivalent or superior performance.▪

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The shortening strain study measurements referenced in this article are from: Liljestrom, W. P. and Polivka, M., *A Five-Year Study of the Dimensional Stability of Shrinkage-Compensating Lightweight Concrete Used in Post-Tensioned Slabs*, American Concrete Institute, Special Publication SP-38-13, January 1, 1973, pp. 273-288.