PROGRESSIVE DETERIORATION CAUSED BY POOR QUALITY CONTROL AND INADEQUATE MAINTENANCE: THE SAD TALE OF A DOOMED PARKING STRUCTURE

By

GREGORY P. CHACOS

POST-TENSIONING INSTITUTE ®

Authorized reprint from: August 2009 issue of the PTI Journal

Copyrighted © 2009, Post-Tensioning Institute
All rights reserved.

PROGRESSIVE DETERIORATION CAUSED BY POOR QUALITY CONTROL AND INADEQUATE MAINTENANCE

THE SAD TALE OF A DOOMED PARKING STRUCTURE

by Gregory P. Chacos

This is a case study of a 2200-car, municipally-owned, cast-in-place, post-tensioned parking structure, opened in 1975 and demolished in 1994 because of severe deterioration. A review is made of significant features of the design, construction, and maintenance as they relate to the deterioration. The number and timing of broken strands (tendons) is given, as are descriptions of the incremental shoring that was installed and the demolition.

INTRODUCTION

In 1985, the author was retained to investigate the cause of a broken strand that was an impediment to traffic in a municipally-owned, 10-year-old public parking facility (Fig. 1). An initial inspection revealed the presence of six broken strands, but there was no record of when the first five occurred.

Regular inspections were made during the next 6.5 years to document the new breaks and to collect other information needed to evaluate the serviceability of the structure. The facility was located in a northern area of the U.S. where the use of chemical deicing compounds is common.

The engineer-of-record for the overall facility was not available for participation in the investigation, nor was the designer/supplier of the post-tensioning materials.

DESCRIPTION OF THE STRUCTURE

This was a four-story, partially embedded, cast-in-place concrete structure, 820 ft (250 m) long in the east-west direction, 192 ft (60 m) wide, with concrete walls on all sides (Fig. 2).

The decks were post-tensioned flat plates with shear drops on 24 x 36 in. (610 x 915 mm) columns on a 30 x 32 ft (9.1 x 9.8 m) grid. The three intermediate slabs, L1, L2, and L3, were 8.5 in. (215 mm) thick. The top deck used 10 in. (250 mm) slabs with a membrane and protective slab, and the bottom level was a simple slab-

Fig. 1—Broken strand popout.

on-ground. The intermediate levels were not covered with a membrane.

The slabs were divided into five areas by north-south expansion joints spaced from 121 to 211 ft (36.9 to 64.3 m). Lateral stability was provided by a combination of shear walls and frame action developed by the slabs and columns. Travel between levels was provided by local ramps along the south edge and by a spiral ramp at the west end.

The south wall retained three to four stories of earth but this gradually decreased to nothing along the east and west walls. The north elevation was a solid concrete wall four stories high (Fig. 3).

Access was available on the south, east, and west sides, but the east and west entrances were closed after the first few years of operation for reasons related to security and economy.

DESIGN

The structure was designed using ACI 318-71, "Building Code Requirements for Reinforced Concrete." The critical slabs on the intermediate levels were designed for

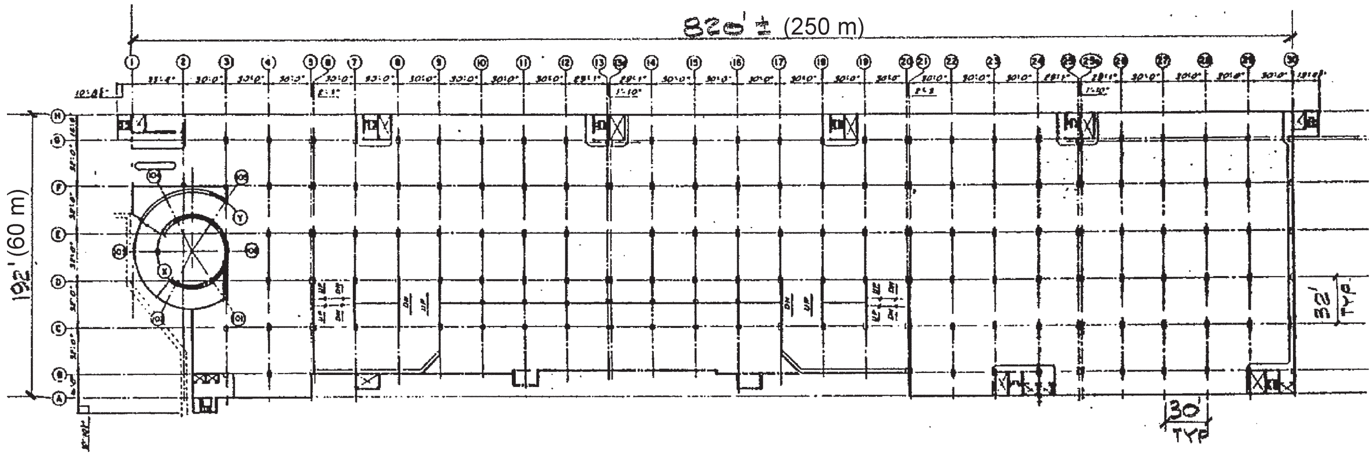

Fig. 2—Plan.

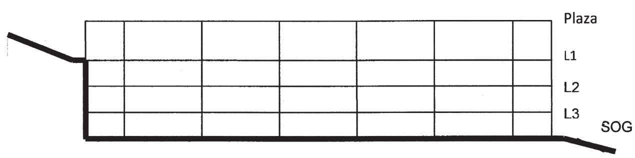

Fig. 3—Section.

a live load of 50 lb/ft^2 (2.4 kPa) using a concrete cover of 1 in. (25 mm). The design of all post-tensioned slabs was performed by the supplier of the post-tensioning materials. The framing plans were appropriately stamped by the designer with his professional engineer seal and these drawings became part of the as-built set.

The tendons were 0.5 in. (12.7 mm) 270K monostrand tendons with heat-sealed strip sheathing, a configuration that was in common use before encapsulated tendons became available. The tendons were placed in a woven pattern similar to that used for placing bonded reinforcing bar in non-post-tensioned flat plates and flat slabs.

The design was typical of the time but the average compression was only 141 psi (1 MPa) in each direction, which is approximately 25% less than what would be considered prudent today for a northern parking structure. The slabs were supported on the perimeter walls. Details to accommodate early slab shortening were provided at the slab-to-wall intersections, but these were cast solid shortly after the strands were stressed. Expansion joints isolated the stair towers and elevator shafts.

Surprisingly, few cracks were found that leaked. Most of these were midway between expansion joints, were relatively straight, and ran most of the full north-south dimension. A few cracks were found near the extreme corners.

INVESTIGATION

Tests and inspections were performed during the initial investigation to determine the strength and chloride content of the concrete, the concrete cover, and the location of spalls. Strand sheathing was tapped in some locations to check for the presence of water, and a close inspection was made of the top and underside of the slabs to find signs of broken strands. Subsequent inspections were performed yearly at first but the increment was steadily reduced to every few weeks as time went on.

Core tests found the concrete to be relatively uniform, of acceptable quality, with compressive strength in excess of 5000 psi (35 MPa). Chloride content was approaching a significant level but of more concern was the lack of appropriate concrete cover. It was found that the top layer of reinforcing bar, and sometimes strands, had less than 0.5 in. (13 mm) of cover. The non-post-tensioned circular ramp suffered deterioration from lack of cover also, so the cover deficiency was not limited to the parking slabs.

Water was found at the low part of the drape in many of the strands that were tapped. The sampling was minimal, as gaining access to the strands was a tedious process because of difficulty working overhead through relatively hard concrete.

STRAND BREAKS

Broken strands were identified by popouts that occurred when the strand recoiled within its sheathing and broke through the concrete cover. Most of the time, the entire strand was visible but sometimes only a single wire identified the break. Most of the popouts occurred through the top surface but some came through the soffit. Sometimes two or three strands failed in the same location, presumably at or approximately the same time. No effort was made to determine the location of the break along the length of the tendons.

Broken strands were found with increasing frequency as time passed (Fig. 4). (It was not feasible to determine how many broken strands did not popout and were therefore not found.)

The rate of breaks found varied from two per year initially to 36 per year less than 7 years later. The records that survive are not complete enough to separate the breaks to each level, but approximately half the total number of breaks were found in Level L1. (The few broken strands in the top level were in beams along the expansion joints and were ignored for this study.)

Figure 5 shows the author's favorite strand. It was monitored in this condition, with pitted and dented wires, for nearly 2 years before it broke. (The strand was checked for tension with a large screwdriver during each inspection.) It was midway between columns in a turning lane, was nearly always wet, and was exposed to abrasion by automobile tires 5 days a week. The cover over this strand was less than 0.5 in. (13 mm).

MAINTENANCE

The expansion joint seals used nonrecessed glands several inches wide. Many, especially those in the top level, had been damaged and not repaired by the time of the first inspection. The trench drain at the main entry was found to be clogged, allowing copious amounts of water to run into the facility at intervals all year long.

The decks were cast without slope and even though deflections were small, usually less than 0.75 in. (19 mm), shallow puddles were commonly found at midpanel. There were no floor drains because the owner had taken a credit for them when the bids came in high. A wet-vacuum tanker truck was originally used to remove water from the floor but this system failed after a few years when the vehicle was retired because the cost of repairs was judged to be excessive. Thereafter, no effort was made to deal with water that came into the facility.

The expansion joint seals were not maintained after the initial warranty period and had been leaking for years by the time of the first inspection. Likewise, the many spalls that exposed tendons and reinforcing bar had not been repaired.

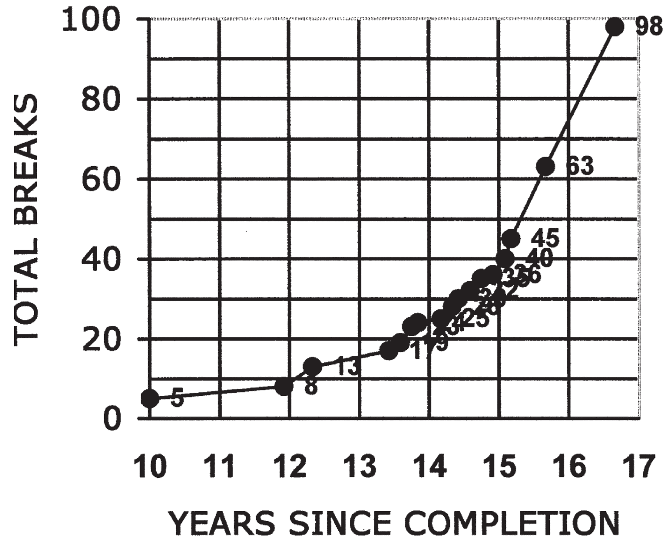

Fig. 4—Total strand breaks found from 1984 to 1991.

Fig. 5—Exposed unbroken strand in traffic lane.

SHORING

The strength of the various slabs was evaluated as the broken strands were found. There were 16 tendons per bay in the north-south direction and 17 tendons per bay in the east-west direction. Shoring to ground was installed when the lost tendons reduced the live load capacity to 25 lb/ft^2 (1.2 kPa). Shoring began in 1988 and had been augmented seven times during the next 4 years, by which time approximately one-third of the intermediate slab areas contained shoring. Parking operations continued even though traffic was severely hampered, parking spaces had been lost, and impact damage to the shores was routine.

PROPOSED REPAIRS

Repair schemes were presented at intervals during the monitoring period but none were authorized. The final scheme, developed in 1992, involved ignoring the existing tendons, removing rusted reinforcing bar, adding new tendons through slots in the slab to place them above the slab at the columns and below the slab at midspan, adding a bonded topping to cover the new tendons and reinforcing bar and to provide positive drainage, adding a drain in each panel, applying a membrane, and encasing the tendons beneath the slab. The author had used this same technique with success for various situations during the previous 15 years. The concept, however, was rejected because the owner was convinced the slabs would cause more trouble later.

The owner sought the council of other engineers who were of the opinion that the intermediate slabs should be removed and replaced. This scheme was investigated and found to approximately the cost of a new facility. Shortly thereafter, a new source of funding became available, so the owner condemned the structure and had it replaced. The new structure is open on three sides and uses a conventional, post-tensioned, long-span beam and one-way slab system.

CONCRETE INSIGHTS CORP.
MATERIAL EXPERTISE, CONCRETE WISDOM

General Civil Design with Specialty in Concrete and Plaster

Concrete Damage Evaluation
- Earthquake ▪ Fire ▪ Flood/Water ▪ Soil
- Sulfate Attack ▪ Condition Surveys
- Alkalai-Aggregate Reaction
- Construction Defects

Services
- Evaluation of Damage ▪ Investigations
- Reports Conferences ▪ Depositions
- Trial Testimony ▪ Engineers ▪ Geologists
- Scientists ▪ Technicians ▪ Drafters

1040 E. Howell Avenue
Anaheim, CA 92805

T: (877) 231-1020 info@concreteinsights.com
F: (714) 634-4933 www.concreteinsights.com

DEMOLITION

The author was retained as a consultant to the demolition contractor. Difficulties arose because some of the stair towers had been doweled into the slabs, apparently due to yet another misinterpretation of details on the drawings. Once that matter was identified, the process went as close to plan as possible. The structure was brought down with a wrecking ball in a series of progressive collapses of bay-wide areas. No tendons were cut prior to or during the process.

Inspection of the debris at various stages of demolition confirmed the author's experience that the strand in monostrand tendons do not break during demolition, nor do the wedges become dislodged. Many severely corroded anchors were found but none were found to contain, or be in the vicinity of, broken strand—even when the wedges were so corroded as to be barely recognizable.

Unsheathed strand, covered with emulsified grease with a soap-like consistency, was commonly found adjacent to the fixed and stressing anchors, but these sections of strand were never found to be broken. The strand breaks that could be found among the debris were always rusted, indicating that the breaks occurred before demolition.

SUMMARY

The history of this structure illustrates a few of the bad things that can happen when common sense and good engineering practices are not followed. This facility could still be in service if it had been built in closer accordance with the drawings and received reasonable attention to maintenance and repair.

There was no litigation in connection with this project.

PTI Fellow and Professional Member **Gregory P. Chacos** *is a consultant for G. P. Chacos, PLLC. He received the 2009 Ken Bondy Award for Most Meritorious Technical Paper. His research interests include structural design of prestressed concrete and post-tensioning.*