

Condition Assessment of Unbonded Post-Tensioning Strands

A case study using nondestructive testing to evaluate the floor slab of a parking structure

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Our company, Walker Restoration Consultants, recently performed a condition assessment on a post-tensioned slab of a parking structure in Wisconsin. We used three nondestructive testing (NDT) techniques to evaluate the same area of the slab, and we cut exploratory openings at selected locations. This allowed us to compare the results of NDT techniques and confirm our diagnoses with visual assessments of the strands in exploratory openings.

STRUCTURAL SYSTEM

The parking structure was built in four different phases from 1976 to 1988. The current structure is 571 x 242 ft (174 x 74 m) in plan and provides parking for about 1450 cars on one ground level plus four elevated levels. The elevated levels consist of post-tensioned slabs, each about 6 in. (150 mm) thick, supported by post-tensioned beams and cast-in-place columns. Although our condition assessment was for the full structure, the current discussion will focus on our evaluation near a construction joint in the first elevated level of the structure. This construction joint is in the middle of a bay that is about 60.5 ft (18.4 m) wide and 200 ft (61 m) long (Fig. 1). No original construction drawings or documentation of past repairs were available for the structure.

INITIAL OBSERVATIONS

During our initial walk-through, we observed full-depth cracking and localized delamination of the slab. In addition,

we noticed grease stains on the underside of the slab in line with post-tensioning strands embedded in the slab. At the expansion joint between Grid Lines 11 and 12, the exposed ends of the strands and the end anchorages were partially visible. At this expansion joint, corrosion products were visible on exposed post-tensioning elements, and some of the strands had missing wires and reduced cross-sectional areas.

The condition of the construction joint between Grid Lines 6 and 7 also provided preliminary clues about the condition of the embedded post-tensioning. Although the upper slab surfaces were at the same elevation on each side of the construction joint, we noted that the slab soffits were not vertically aligned (Fig. 2). We surmised that the vertical offset was not the as-built condition. Rather, it seemed that one side of the slab had deflected over time, and the upper surface had been patched to maintain a smooth riding surface (Fig. 3). To confirm this hypothesis and identify probable causes for the differential deflection, we undertook a thorough condition assessment using NDT evaluation of the post-tensioning strands and intermediate anchorages at the construction joint.

ASSESSMENTS

We considered a range of NDT techniques for evaluating potential strand breakage. Based on the scope of the investigation, budget constraints, and statistical

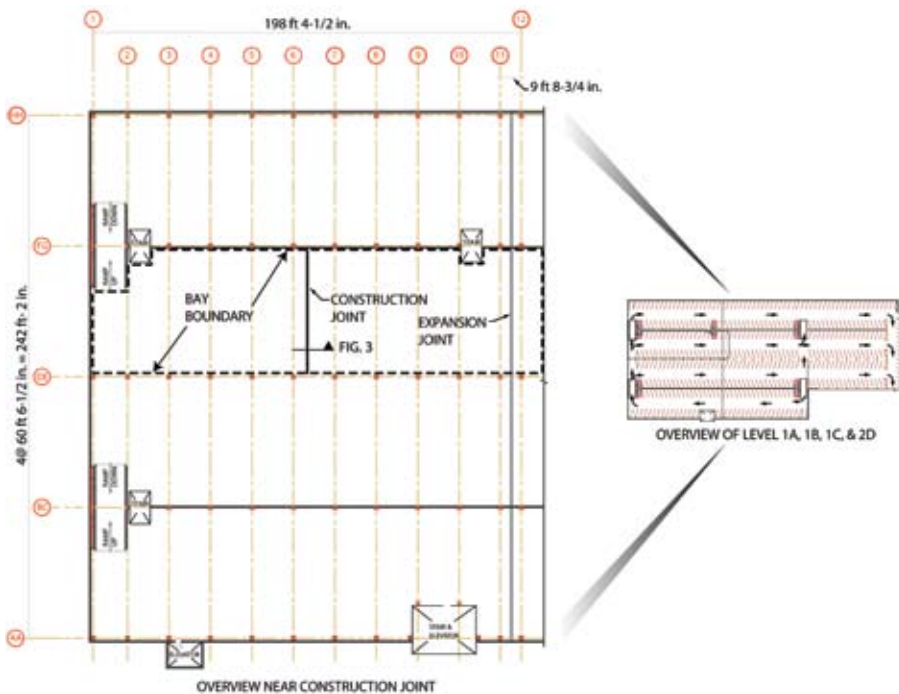


Fig. 1: Plan of the parking garage showing the area of the post-tensioned floor slab that was investigated with various NDT techniques



Fig. 2: Differential in the elevation of the bottom of the slab at the construction joint

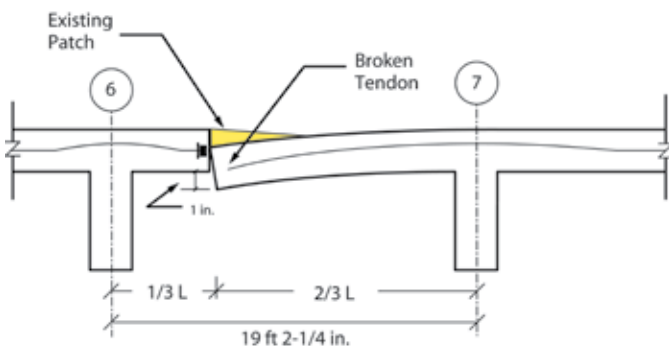


Fig. 3: Illustration depicting the differential in the elevation of the bottom of the slab

considerations, we selected ground-penetrating radar (GPR) as the primary NDT method. We selected x-ray radiography and magnetic scanning using the Ferroskan[®] system manufactured by Hilti Corp. as secondary methods. An independent testing agency with certified NDT personnel was contracted to perform GPR and x-ray evaluations, and engineers from our office conducted magnetic scanning. To confirm the results from the NDT techniques, limited destructive testing was also performed by making exploratory openings.

GPR mapping

As a GPR instrument is rolled over a surface, the device transmits short pulses of electromagnetic energy into the underlying material.¹ A portion of the transmitted energy is reflected at the interface of

materials with dissimilar dielectric properties. The contrast in the dielectric properties governs the properties of the reflected pulse, allowing the depth and location of the interface to be determined.

A 1.5 GHz nominal frequency antenna was used, and multiple scans were performed to locate embedded strands and search for breakages. Figure 4 presents results from a typical GPR scan, showing embedded strands along with steel reinforcing bars. GPR data indicated that post-tensioning strands were spaced at about 2 ft (0.6 m). Our analysis of the GPR data indicated that 4 of the 24 located strands were severed (Table 1).

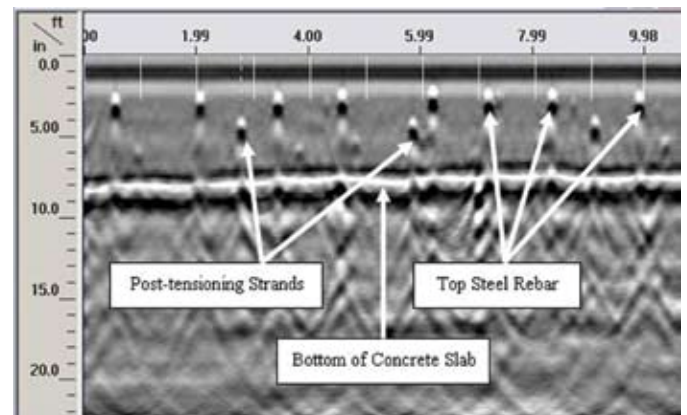


Fig. 4: Typical GPR scan showing embedded strands and reinforcing bars

TABLE 1:
NDT RESULTS FOR SLAB POST-TENSIONING STRANDS

Strand number	Assessment method			
	GPR mapping	Magnetic scanning	X-ray radiography	Exploratory opening
1	Intact	—	—	—
2	Severed	Severed	Severed	—
3	Intact	Intact	—	25% section loss, heavy pitting corrosion
4	Intact	Intact	Intact	25% section loss
5	Intact	Intact	—	25% section loss
6	Severed	Severed	Severed	—
7	Intact	Severed	—	Severed
8	Intact	—	—	—
9	Intact	—	—	—
10	Intact	Severed	Severed	—
11	Intact	Severed	Severed	—
12	Intact	—	—	Severed
13	Severed	—	—	Severed
14	Severed	Severed	Severed	Severed
15	Intact	Severed	Severed	Severed
16	Intact	Severed	—	Severed
17	Intact	—	—	Severed
18	Intact	—	—	50% section loss
19	Intact	—	—	—
20	Intact	—	—	Severed
21	Intact	—	—	—
22	Intact	—	—	—
23	Intact	—	—	—
24	Intact	—	—	—

Note: An em dash (—) indicates no evaluation was conducted using indicated assessment method.

Magnetic scanning

When a magnetic scanner is rolled over a concrete slab to locate reinforcing steel and strand, the steel causes disturbances in the magnetic field produced by a magnet in the base of the scanner. These disturbances are detected by sensors in the scanner and are automatically recorded as a function of the position of the unit. After performing a second scan perpendicular to the first, a processor displays the recorded data as a two-dimensional image showing the location of the bars and strand on the unit's console.

Eleven randomly selected strand locations were scanned. The results indicated eight severed strands (Table 1). The analysis of the magnetic scans also indicated that the strands near the breaks were on average 2.1 in. (56 mm) below the surface. A typical image of a severed strand, with a gap between the strand

and the intermediate anchorage, is shown in Fig. 5.

These results clashed with those from GPR for Strands 7, 10, 11, 15, and 16 (Table 1). For example, although GPR results indicated Strand 10 was not severed, magnetic scans indicated that Strand 10 was severed. Strands 10, 11, and 15 were subsequently scanned using x-ray radiography.

X-ray radiography

When used to evaluate concrete structures, x-ray radiography provides two-dimensional images of embedded, high-density materials such as steel. A radiograph of an intact strand along with the embedded intermediate anchorage and a reinforcing bar is shown in Fig. 6. The high-density material is shown on the radiograph as a white zone, while the concrete appears as a dark area.

A total of seven strand locations were tested using x-ray radiography (Table 1). The images indicated that

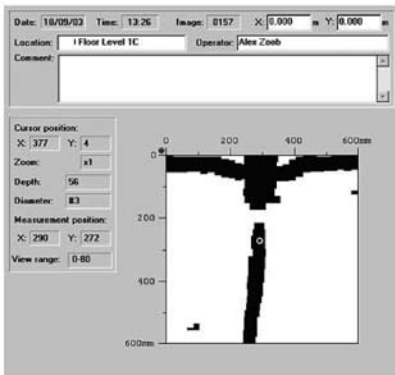
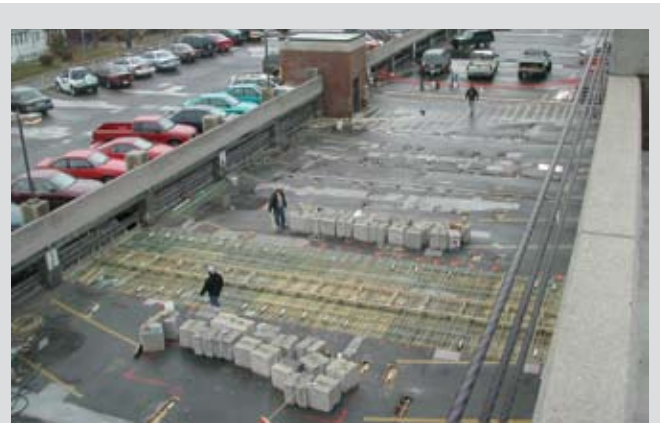


Fig. 5: Magnetic scanning image for a typical severed strand



Fig. 6: X-ray radiograph for Strand 4



THE REPAIR

The parking structure is shown during repair operations. After shoring the slab, the strands were detensioned. The full depth of the existing slab around the construction joint between Grid Lines 6 and 7 was then removed, and the post-tensioned beams were counter-weighted by stacking concrete blocks adjacent to each beam. As the slab dead load was removed, the counter-weights were needed to prevent upward deflection of the post-tensioned beams that could have caused cracking.

Broken or corroded sections of the strands were replaced with new strands. Noncorroded existing strands and new strands were connected using couplers. New live-end anchors were provided at each strand on both sides of a new pour strip so the strands could be stressed from both sides of the new pour strip. After replacing the deteriorated strands and anchorages, full-depth repair areas were patched with concrete. After curing of the concrete, the strands were stressed from the new pour strip.

For each strand, the observed elongation under jacking force was required to be within 7% of the calculated elongation. Excessive elongation signified breakage of some of the wires in the strand and required replacement of the strand. Elongation less than the allowable value indicated that part of the strand was locked up due to corrosion. When this situation occurred, the observed elongation was used to calculate the length of strand under stress, and this length was used to locate where the strand was locked up. An opening was made at this location, thus releasing the tendon so that it could attain uniform stressing over its length (and proper elongation). Any strand broken during stressing was repaired by locating the break and removing the slab at that location, followed by installation of a new coupler and additional new strand.

six of the seven strands were severed, with the break in the tendon appearing as a relatively dark spot in the x-ray image. The x-ray radiography results also matched the magnetic scan results for Strands 10, 11, and 15.

Exploratory openings

We informed our client of the NDT results and recommended that parking on and below the affected areas be closed. Then, to confirm the NDT results, exploratory openings were made at the construction joint to expose the strands. Table 1 presents the findings and observations from the exploratory openings. At the 12 exploratory openings, eight strands were found to be severed. Even worse, six of these severed strands were adjacent to one another. Although intact, the remaining strands showed significant loss of cross section due to ongoing corrosion.

INVESTIGATION RESULTS

The exploratory openings confirmed the results of the magnetic scanning and x-ray radiography. Comparison of the photo of the severed strand in Fig. 7 with the magnetic scan image in Fig. 5 shows that the instrument accurately depicted the existing condition of the severed strand.

Exploratory openings made for Strands 7, 15, and 16 were closely examined to determine why the GPR testing results were not consistent with the conditions observed in the exploratory openings. Our field measurements for



Fig. 7: Severed strand revealed after exploratory opening was made (magnetic scanning image of the same strand is shown in Fig. 5)

these strands showed that the gap at the severed strands (1 to 1.5 in. [25 to 40 mm]) was too small to be detected by GPR. The magnetic scans, however, proved effective in capturing breakage—even with smaller gaps between severed sections of strand. It should also be noted that the depth of embedded strands was less than 3 in. (75 mm). Also, there was no magnetizable material along the strands that also could have disturbed the magnetic field. These factors may have provided additional advantages for detecting the small gaps with magnetic scans.

Exploratory openings also revealed that, while the strands were covered with plastic sheathing along the majority of their length, they were not protected by sheathing near the intermediate anchorages (Fig. 7). Unprotected sections of strand about 4 to 5 in. (100 to 125 mm) long were likely exposed to chloride ions from deicing chemicals. Most of the strands had lost a significant percentage of their cross section at this location. ACI 423.4R-98, “Corrosion and Repair of Unbonded Single Strand Tendons,”² notes that it was common practice to stop the sheathing short of the anchorages at the time of the original construction of the parking structure.

With such a high percentage of severed strands and strands with significantly reduced cross sections, the load carrying capacity of the floor slab was considerably reduced. Per our recommendation, the floor slab was shored and repairs were made to the post-tensioning system and concrete.

LESSONS LEARNED

Condition evaluation of the parking structure slab post-tensioning using NDT and limited destructive testing provided the following lessons:

- Post-tensioned tendons and anchors embedded in a floor slab at a construction joint are highly prone to corrosion, especially if portions of the embedded strands are unsheathed. Therefore, when evaluating structures, pay special attention and review background documents related to post-tensioning;

- Observations of vertical offset in the slab, concrete distress, or corrosion in the proximity of construction joints in a post-tensioned slab could be signs of post-tensioning failure. Therefore, thoroughly evaluate areas near distressed construction joints;
- NDT can be a valuable tool to help assess the condition of embedded post-tensioning. While GPR can effectively pinpoint the location of embedded post-tensioning in a floor slab and can generally detect severed strands, it may not be able to identify small gaps (less than 1 to 1.5 in. [25 to 40 mm]) in strands; and
- Magnetic scans can effectively detect severed strands at shallow depths (0 to 3 in. [0 to 75 mm]) and can, with the right conditions, identify small gaps at severed strands.

References

1. ACI Committee 228, “Nondestructive Test Methods for Evaluation of Concrete in Structures (ACI 228.2R-98),” American Concrete Institute, Farmington Hills, MI, 1998, pp. 21-25 and 38-45.
2. ACI Committee 423, “Corrosion and Repair of Unbonded Single Strand Tendons (ACI 423.4R-98),” American Concrete Institute, Farmington Hills, MI, 1998, pp. 6-7.

Selected for reader interest by the editors.



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