*PTI Journal* *Technical Paper*

# NON-DESTRUCTIVE TESTING OF UNBONDED POST-TENSIONED TENDONS

By

J. MILLER AND A. SCOTT

POST-TENSIONING INSTITUTE ®

Authorized reprint from: December 2006 issue of the PTI Journal

# NON-DESTRUCTIVE TESTING OF UNBONDED POST-TENSIONED TENDONS

JOHN P. MILLER AND ALAN R. SCOTT


## ABSTRACT

Many post-tensioned parking structures that were designed and constructed in the early days of post-tensioning technology are now thirty to forty years old and, depending on the level of care and maintenance they have received over the years, may be at or nearing the end of their expected useful life. The Owner of one such thirty-two year old, post-tensioned parking structure in the Midwestern US had, over the years, replaced broken tendons that manifested themselves by popping out of the end of the structure or by breaking through the concrete cover. The Owner wanted to gain confidence that the old structure had enough remaining service life to be safely used until a replacement structure could be designed and constructed within a three year period. This was of particular concern to the Owner since the structure was designed and built with no top, bottom, or temperature mild steel reinforcing in the PT slabs. A simple, fast, and economical non-destructive testing program was initiated to determine the condition of, and level of prestress force in, the slab tendons.



## KEYWORDS

concrete; post-tension; prestress force, test; unbonded tendon;.


PTI Journal, V. 4, No. 2, December 2006. Received and reviewed under Institute Journal publication policies.  Pertinent discussion will be published in the next issue of the PTI Journal if received within 3 months from the publication.

## 1.0 INTRODUCTION

Post-tensioned parking structures gained wide popularity in the 1970s for many reasons, including the ability to achieve longer spans, use of thinner members, reduced deflections, and minimal cracking. Since the early days, corrosion protection technology has made great advancements and many lessons have been learned in detailing of post-tensioned structures to minimize required maintenance and repairs. Arguably, the leading causes of deterioration of concrete parking structures are moisture and chloride infiltration. Parking structures are continuously attacked by these elements, and once they infiltrate into the concrete members through cracks, pores, or tendon anchorages, structural degradation begins. Corrosion of tendon wires and tendon anchorages can lead to the complete and sudden loss of prestress force in a tendon. Loss of post-tensioning force in one or two randomly located tendons generally does not pose an immediate structural concern, although standard practice is to replace them. However, broken tendons may point to systemic and active degradation in the structure. It is not uncommon when a tendon breaks to manifest itself by popping out of the end of the structure or anchorage (see Fig. 1), or by breaking

Fig. 1 – Visual Indication of a Broken Tendon

through the concrete cover within the confines of the structure. Since broken tendons are not always obvious, it cannot be readily determined based on visual examination alone whether the tendons in a structure are intact, and if so, what amount of prestress force they hold.

This paper describes a non-destructive method to observe the condition of potentially damaged unbonded slab tendons in an existing structure and determine the approximate amount of prestressing force they hold. The testing described was performed on a thirty-two year old parking structure in the Midwestern US that was built in 1973. The test procedure was adapted from a paper written by Gupta1 in the PTI Journal. This simple and economical test method can be very effective in determining the force contained in single slab tendons, but would need to be adapted for beams or otherwise bundled tendons.

## 2.0 EXISTING GARAGE CONSTRUCTION

The existing structure is a four-level, cast-in-place post-tensioned concrete parking structure with approximately 850 parking stalls. The structure is three bays wide with one-way drive isles. The typical column grid is 20 ft by 56 ft. 14in. x 34 in. post-tensioned beams span the 56 ft direction and 5 in. thick post-tensioned slab spans the 20 ft direction. Final effective post-tensioning forces in the beams and slabs were given on the plans, but no specific information regarding the tendons was given. The condition assessment revealed that 0.6 in. diameter unbonded tendons were used in the structure. Observations also indicated that the tendons were greased and sheathed in black plastic. There was an expansion joint running through the middle of a 20-ft bay of the structure, dividing the overall structure into roughly symmetrical halves. The slab cantilevers approximately 10 ft up to the expansion joint from each sides. The beams are reinforced with mild reinforcing steel in conjunction with post-tensioned tendons. However, the design drawings do not show any mild reinforcing steel whatsoever in the slabs. The slabs appeared to rely solely on the draped tendons for support.

## 3.0 CONDITION ASSESSMENT

The first step in understanding the overall structural condition of the parking structure was to perform a condition assessment. This assessment was accomplished in the conventional manner by:

1) Reviewing available structural and architectural drawings
2) Mapping areas of previous deck repairs in accessible areas
3) Chain dragging accessible deck areas to identify areas of concrete delamination
4) Rodding the underside of the deck slabs and beams to identify areas of delamination
5) Taking concrete cores in selected areas to determine the chloride concentration through the slab depth, and
6) Walking the remaining garage to visually observe other elements of the structure.

The results from the condition assessment revealed that the structure was in poor condition. The Owner reported that the garage was not well maintained in the first decade of its service life. Areas of distress included significant and widespread delamination of the top concrete surface, significant concrete deterioration at the pour strips and expansion joints, significant corrosion of top reinforcing steel in the beams, exposure of many tendons due to concrete delamination, a high level of chloride infiltration, efflorescence on the bottom of members, ghosting of the tendons on the bottom of the slab, water infiltration through cracks and tendons, and deterioration of previous repairs. At least one tendon was obviously broken (Fig. 1) which meant others could potentially be broken or corroded. Investigation using a pachometer revealed that indeed the parking structure slabs did not contain any mild reinforcing, either positive bending reinforcement at mid-span, negative bending reinforcement over the beams, or transverse temperature reinforcement.

Given the condition of the structure, the lack of mild reinforcing in the slabs was an area of concern for the Owner. Furthermore, the garage had a history of broken tendons and poor maintenance. Since the slabs relied solely on the draped tendons for support, the Owner decided to conduct further investigation the condition of the existing slab tendons to determine whether the structure would be serviceable over the next three years while a replacement parking garage was designed and constructed. The following testing program was used in the assesment.

## 4.0 TESTING PROGRAM

The method of tendon investigation developed for this structure was to expose small lengths of selected tendons, place a known lateral force on each of the exposed tendons, and measure the amount of lateral deflection of the tendon. One benefit of this test approach is that a visual examination of the exposed portion of the tendons can be made. A screw driver test can also be performed at each test tendon to investigate for any broken individual wires. A free-body diagram of the described test is shown in Fig. 2. Length L was selected as 18 in. Using statics, the prestressing force in the tendons can be calculated using Eq. 1.

$$T = \frac{F}{2\sin(\tan^{-1}\frac{\Delta}{0.5L})} \qquad (1)$$

The influence of the length of unbonded tendon away from the test location was studied. See Fig. 3 for a free-body diagram of this system. The change in tension ?T in a tendon for a given displacement at the test hook can be calculated using Eq. 2.

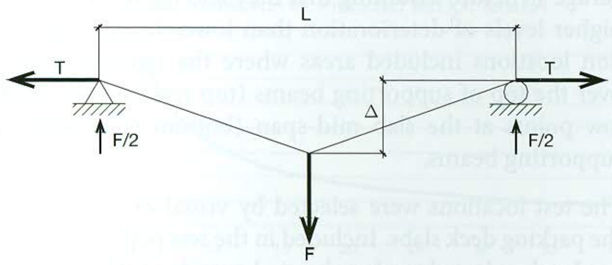


Fig. 2 – Free-Body Diagram

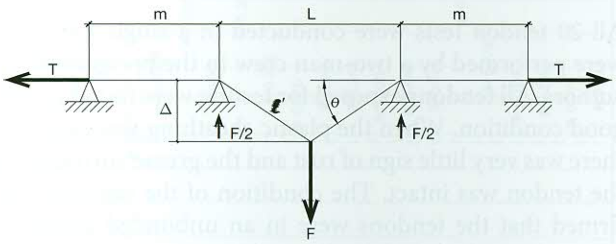


Fig. 3 – Free Body Diagram Including "Unbonded" Length

$$\Delta T = AE\frac{2\ell' - L}{L + 2m} \quad (2)$$

If we set ? equal to 0.19 in. and m equal to 100 ft the increase in tendon tension is theoretically 21 lb. If m is zero, as is assumed in this study (Fig.2), the increase in tendon tension is 1398 lb, or approximately 4% of the expected tendon tension of 35.7 kips. Thus it was deemed that the influence of the length of unbonded tendon away from the test location has a negligible affect on the results.

The basic test for each tendon consisted of locating the tendon, saw-cutting a partial-depth slot in the concrete, carefully chipping away the concrete from around the tendon over a length of approximately 24 in., removing a small portion of the plastic tendon sheathing, installing and calibrating the test apparatus, and finally applying a known force on the tendon and measuring its displacement. The test apparatus shown in Fig. 4 and 5 performed all the required functions of the test by applying the load, measuring the load, and providing deflection measurements via an attached dial gage. Care was taken to make sure all loose concrete, tie wires, slab bolsters, and enough concrete behind the tendon were removed to assure that nothing impeded the displacement of the tendon or movement of

Fig. 4 – Test Apparatus Mounted on Top of Slab

Fig. 5 – Test Apparatus Mounted on Bottom of Slab

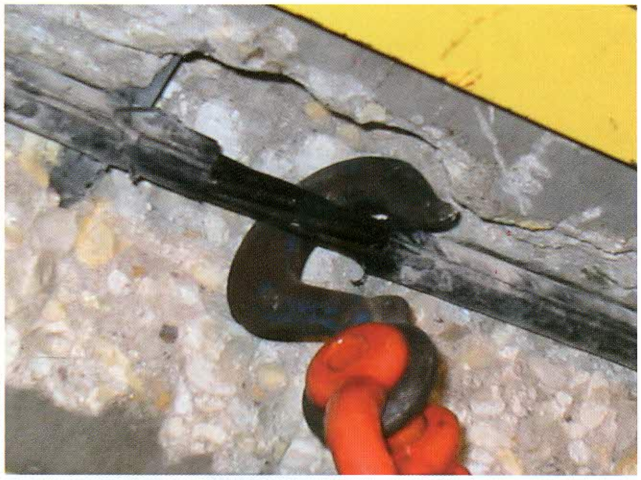

Fig. 6 – Close Up of Test Hook on Exposed Tendon

the test hook. See Fig. 6. The tendons were regreased and rewrapped and the test areas were easily patched at the conclusion of the test.

The load in the hydraulic ram was applied in two increments. First, a load of 1000 lb was applied to the tendon to seat the test apparatus. The dial gage reading was recorded after a short waiting period. Then the ram load was incremented by 1500 lb and another dial gage reading was taken after another short waiting period. The difference in the two dial gage readings yielded the tendon displacement for the applied load increment of 1500 lb. The testing contractor was required to have the hydraulic jack and dial gage calibrated before and after the test to assure testing accuracy.

The original construction documents listed the effective post-tensioning force as 21.4 kips/foot of slab width. The tendon spacing was field verified at 20 in. on center. Thus, the initial design tendon force would have been (21.4 kips) x (20/12) = 35.7 kips. Based on this force, and using Eq. 1, we would expect to see a measured deflection in the tendon of 0.19 in.

### 4.1 DETERMINING THE SAMPLE SIZE

The number of tendons selected for the investigation was established to allow a relatively high degree of confidence that the results would be representative of the condition of all the tendons in the garage, while keeping the testing costs to a minimum. It was estimated that there are approximately 615 primary slab tendons in the garage structure, not including temperature tendons and beam tendons. It was judged that a small but reasonable number of tendons could be selected to provide an adequate level of confidence. Based on statistical information contained in Reference 3, the test population of 20 tendons provided an adequate confidence level that the results would be representative of the entire population of tendons. The tendons selected were on the upper three deck levels of the garage structure assuming that they had been subjected to higher levels of deterioration than lower levels. Test tendon locations included areas where the tendons draped over the top of supporting beams (top test), and at drape low points at the slab mid-span (bottom test) between supporting beams.

The test locations were selected by visual examination of the parking deck slabs. Included in the test population were randomly selected tendons located outside of the drive lane to minimize traffic disruption. Also included were tendons which had been exposed via spalling of concrete cover to investigate whether this was an indicator of corrosion or a broken tendon.

### 5.0 TEST RESULTS

All 20 tendon tests were conducted in a single day. Tests were performed by a two-man crew in the presence of the authors. All tendons exposed for testing were found in very good condition. When the plastic sheathing was removed, there was very little sign of rust and the grease surrounding the tendon was intact. The condition of the tendons confirmed that the tendons were in an unbonded condition rather than a bonded condition. The results of the screw driver test on all 20 tendons indicated that no wires within the test tendons were broken.

The pull tests were performed and the procedure went smoothly, with no problems or disruption. The expected deflection was theoretically established as 0.19 in. at the load increment of 1500 lb. The actual measurements and range of data are shown in Fig. 8. Most measured deflections were slightly higher than the expected results. The average deflection of all tested tendons was 0.25 in. There were three tests where the measured deflection exceeded 0.30 in., with a maximum test deflection of 0.37 in.

Fig. 9 shows the calculated tendon tension compared to the expected tension (final design tension specified on the structural drawings). The expected tension is 35.7 kips, while the average of all 20 tests was 30.0 kips. The lowest tendon tension measured was 20.1 kips and the highest was 43.1 kips.

As a benchmark, two additional tests on a tendon known to be broken were performed. The two tests were conducted on the same tendon from Fig. 1 in two different locations along the length of the tendon. This particular tendon was a slab temperature tendon and extended the full 170-foot width of the structure. One test was conducted approximately 10 ft from the end and the other test was conducted at approximately the midpoint of the tendon. In both cases the pulling force never exceeded 200 lb and the tendon was drawn out of the sheathing until the hydraulic ram bottomed out. This verified that a broken tendon would have been easily identified during the testing. This also confirmed that an unbonded condition exists.

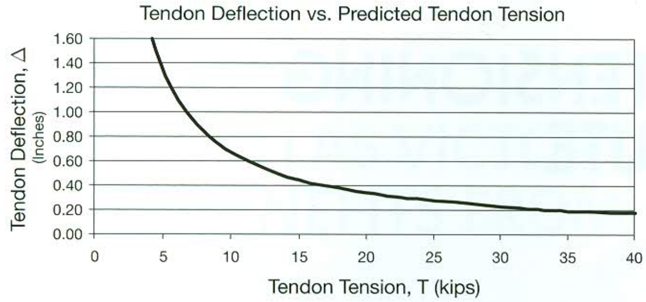


Fig. 7 – Predicted Tendon Displacement vs. Tendon Tension

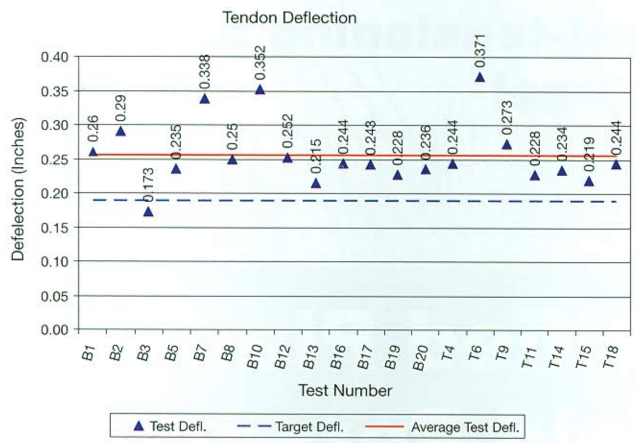


Fig. 8 – Tendon Deflection Test Results

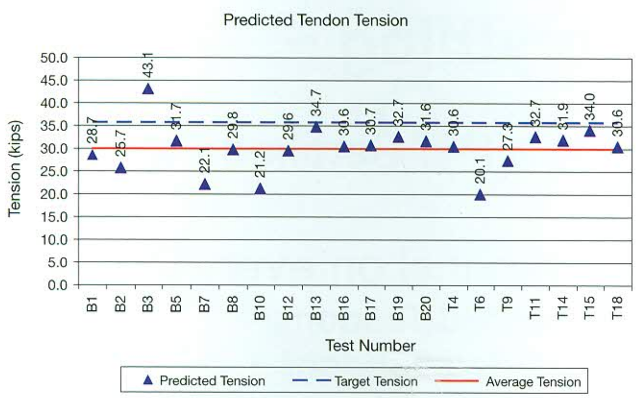


Fig. 9 – Tendon Tension Test Results

## 6.0 INTERPRETATION OF TEST RESULTS

The test results indicate that a significant amount of prestressing force exists in the tendons. No broken tendons were identified from the selected sample. Only 3 out of the 20 tendons tested showed a moderately low amount of prestress force as compared to the expected force. In the worst case, test T6 showed a tension of 20.1 kips of the expected tension of 35.7 kips, or approximately 56%. While this is a significantly low force, randomly located tendons with such a loss of prestress—even complete loss—normally do not significantly affect the serviceability of the parking garage. On average, the amount of prestress force on the 20 tendons tested was approximately 84 percent of the expected force. Based on the test results, it was judged that the parking structure would be serviceable during the 3 year period while a replacement garage was designed and constructed. The Owner was advised to monitor the structure for any changes over the following three year period.

## 7.0 CONCLUSIONS

A non-destructive method of testing post-tension forces in tendons in an existing parking structure was implemented. The test method was found to be simple to conduct and the results were easily interpreted. The procedure also appears to provide consistent and reliable results. The cost of implementing the test procedure on an actual structure was found to be reasonable. This test procedure would need to be adapted for bundled tendons.

## REFERENCES


1. Gupta, P.R., "Field Evaluation of the Prestressing Force in Unbonded Tendons," *PTI Journal*, Vol. 1 No. 2, August 2003, pp 9-14.
2. *Building Code Requirements for Structural Concrete*, ACI 318-99, American Concrete Institute, Farmington Hills, MI, 1999.
3. *Design of Post-Tensioned Slabs with Unbonded Tendons*, Third Edition, Post-Tensioning Institute, Phoenix, AZ, 2004.



**John P. Miller** is a Principal and a founding member of the St. Louis office of KPFF Consulting Engineers. He has over 25 years of experience in the structural engineering consulting industry serving Architects, Contractors, and Developers. John received his Master of Science in Structural Engineering from Washington University in St. Louis and is a registered engineer in fifteen states. He is a member of the American Society of Civil Engineers, the American Institute of Steel Construction, and the Post Tensioning Institute.

**Alan R. Scott** is a registered Professional and Structural Engineer with over 25 years experience. He holds both a BSCE in Civil Engineering and a Master of Engineering degree. Mr. Scott has extensive experience in seismic evaluation, seismic retrofit, and seismic risk analysis, both in California and the Midwest. He also has extensive experience with the evaluation and renovation of turn-of-the-century and historic buildings. Mr. Scott is a founding Principal of the St. Louis Office of KPFF Consulting Engineers.