Observations from 30 Years of Inspecting Post-Tensioned Structures

by Bruce Osborn, Structural Technologies LLC/VSL

During the 1970s, the construction of post-tensioned (PT) concrete structures rose in popularity as the technology allowed for the efficient construction of longer spans with smaller concrete sections and less mild-steel reinforcement. While this technological advancement has provided contractors and owners with a durable and cost-effective solution, it has not been without its challenges.

Since their inception, post-tensioning technology and specifications for PT bridges have evolved to ensure that long-lasting structures are being built with higher-quality installation procedures. Early failures of PT systems such as the Niles Channel Bridge (1999), Sunshine Skyway Bridge (2002), Varina-Enon Bridge (2007), and Mid-Bay Bridge (2011) pushed owners to implement closer inspection of PT systems.

The following article shares the author's firsthand accounts of inspections of over 70 bridges and approximately 18,500 tendons. The author has inspected PT structures in some of the most benign and harshest environments from Alaska to Puerto Rico, and in many locations in between. The condition of each PT bridge was determined through analysis of data gathered from destructive and nondestructive investigations performed on external and internal post-tensioning systems. In the former type of system, tendons run within the void in box girders or cable-stayed bridges; in the latter type, ducts for tendons are cast within the structural concrete section. The findings illustrate the evolution of PT structures since the 1970s, common types of deficiencies, and how shifts in quality-control procedures have improved installation and extended the life of PT structures.

Figure 1. Bare strand in a tendon at a grout void. All Figures: Bruce Osborn.

Unforeseen Challenges

In the early years of post-tensioning, stressing was regarded to be the most important aspect of the operation, and other details were believed to not be as structurally significant. Even though grouting served as another layer of protection against corrosion of the PT strands, it was often treated as an afterthought and performed with limited supervision or inspection from an outside party. Because the construction and inspection standards of past decades do not meet today's requirements, inspection of older PT structures is important.

Prior to 2000, grout used for tendons was a simple mixture of Type I or II cement and water. In some cases, additives were used to try to improve the protective characteristics of the grout. In later years, it was proven that this combination of materials had segregation issues that caused excessive bleeding in the tendons. The presence of bleed water increased the risk of voids during the grouting process, thereby making the strands vulnerable to corrosion. Voids discovered in this time period were typically credited to excessive bleed water, improper venting, poor grouting practices, or inadequate grout materials.

Notably, when inspections identified voids in the grout within tendons, those voids were not always associated with significant corrosion. In most cases, voided areas could be regrouted to extend the service life of the structure and the PT system within it. **Figure 1** shows a borescope picture taken from the inside of a voided tendon in a structure whose exterior condition was well maintained. The void is located at the top of the duct, and the steel within the tendon has not undergone any major corrosion. This type of void is most

Figure 2. Bare strand with clear signs of corrosion in a tendon with a grout void.

Figure 3. Operation to find cracks in the bridge that were leading to moisture in post-tensioned tendons.

Figure 4. Equipment used to pressurize tendons and find the source of water.

often caused when improper grout venting results in air entrapment at a high point. To repair this type of condition, grout ports are drilled into the duct and vacuum grouting is used to ensure a proper seal. When there is seemingly no corrosion, this manner of repair is very beneficial.

Of the bridges inspected, tendon deterioration could typically be attributed to severe cracking of the deck surface at pier locations, which allowed contaminants to enter the metal duct and access the grout and tendon. As water entered the duct, it often traveled the length of the tendon in a process known as "wicking"; this same process can also occur in the seam of a metal duct. **Figure 2** shows an example of corrosion caused by water traveling along the strand and duct into the voided area. In areas where road deicers are used, this phenomenon is a major concern. Once project stakeholders became more aware of this issue, inspections were performed more regularly on this structure's PT tendons. Analysis of the damaged condition by qualified engineers is also prudent.

Noteworthy Findings

Inspections of structures constructed during an era with lower grouting installation standards and supervision illustrate how tendons that were poorly grouted have held up over time. These structures were of different construction types, ranging from precast segmental concrete to cast-in-place concrete boxes on falsework and straddle bents. In one Midwestern state, 17 structures and 233 tendons were inspected. The tendons contained 466 anchorages and 340 high points. For all of the bridges and tendons inspected in this state, 61 voids were located—with some being in the same tendon at different locations. Despite the number of voids found, there were no documented strand or tendon failures in these structures, most likely because of details of the structural high quality of the structure's upkeep. The owner is currently in the process of having the voided areas grouted and the decks sealed to lengthen the service life of these structures.

Inspections by the author have also revealed that a substantial number of the observed tendons with section loss arose from conditions outside of the PT system itself. Cracks, which occur throughout the life of the structure, can accelerate the intrusion of environmental risks to the PT system. Environmental conditions or the general upkeep of the structure surrounding the PT tendons, and not the PT tendons themselves, were typically the root cause. Tendons that are sealed performed much better.

Figures 3 and **4** show two photos from a structure in which large amounts of water collected in the PT ducts. It was not known how the water was infiltrating the system, but there were fears that the PT system was at fault. As part of the investigation, ports were installed into the ducts, which were then pressurized, to seek the source of the water intrusion. After reaching around 40 psi, water began discharging out of the top deck of the bridge (soap was placed around area to make any exiting air visible). This evidence demonstrated that the water-filled ducts were being recharged through cracks in the bridge deck.

One of the most prevalent design problems in PT bridges is scuppers and deck drainage systems that run inside the structure or terminate at critical locations on the superstructure. Over time, these drains fail, transferring road deck debris and water either to the interior of the structure or

Figure 5. Signs of tendon corrosion near a bridge drainage system.

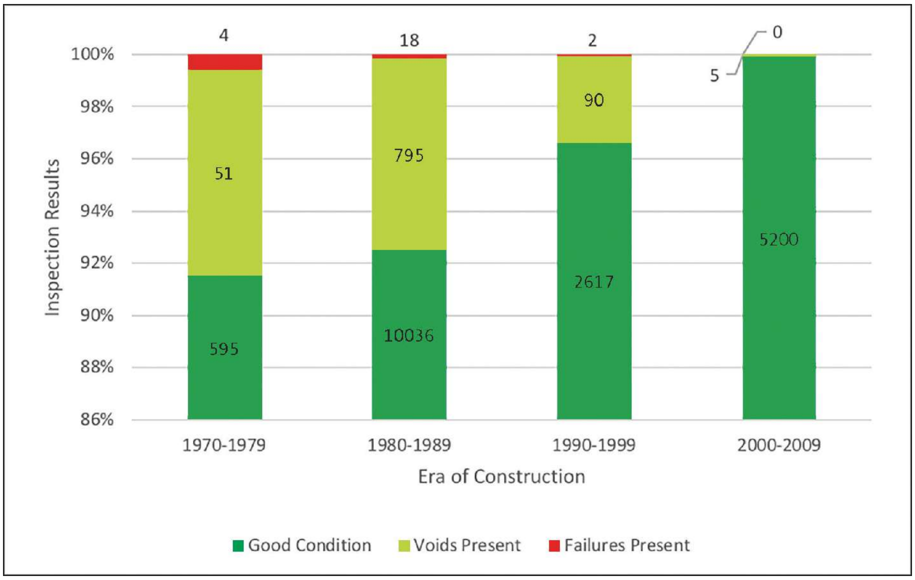

Figure 6. Condition of post-tensioning tendons inspected by the author by construction time period.

onto the superstructure (**Fig. 5**). Cracks consistently exposed to outside contaminants such as road salts and chlorides will grow, further endangering the tendon.

One example of a bridge with a PT system with severe tendon corrosion was the Cline Avenue Bridge, a cast-in-place concrete box structure built on falsework. For several years before the tendon failure was found, inspections had noted deterioration, which was related to a leaking drainage system. Staining was visible on the wall where the water collected because the structure did not contain drain holes. Also, layers of salt were visible on the floor from the leakage and rehydration process. At some point, workers tied rags wrapped with duct tape to the leaking drainage pipe in an attempt to seal it. When it was determined that tendons were located in the same area as the leak, an inspection was performed.

When the Oneida River Crossing structure was inspected in 2007, a few tendon failures were identified. This structure is one of the oldest PT girder-type structures in the United States, built in the 1960s. In this case, the drain scuppers were terminated just above the girder flange and the tendons were encased in a galvanized metal duct. Years of deicing salts applied to the roadway and spreading onto the concrete flange caused the concrete to deteriorate, followed by corrosion of the duct and ultimately corrosion of the tendon. There was no indication of voids being originally present in the failed area.

Advancements in Post-Tensioning

Although tensioning of the tendons is perhaps the most important factor for the strength of the structure, grouting is the most critical for the lifespan and durability of the structure. In the current era, several modifications have been made to improve PT installation and help eliminate issues in the tendons. One major achievement was the introduction of the plastic extruded duct material with airtight sealed connections. This innovation helps prevent intrusion of water or any outside contaminants into the tendons. Another advancement was the introduction of prepackaged thixotropic grouts. These new grouts have limited chloride content, low permeability, zero bleed and excellent pumpability in normal grouting operations.

Another achievement over the past 30 years has been the proactive approach of the American Segmental Bridge Institute (ASBI) and the Post-Tensioning Institute (PTI) to improve the quality of grouted PT structures. These two institutions have developed and continue to refine grouting specifications and procedures as well as field certification programs aimed at eliminating problems with improper materials and incorrect installation of grouted systems. These efforts have served to better educate all parts of the industry and to improve grouting quality. PT tendons are now being grouted under strict guidelines, and detailed reports are required on the grouting operation itself. Testing throughout the operation is required in most states; therefore, if any issue arises in the future, it should be possible to retrieve the original records for investigations. The current state of the practice for grouting can be found in PTI M55.1-12, *Specification for Grouting of Post-Tensioned Structures*, as well as PTI/ASBI M50.3-12, *Guide Specification for Grouted Post-Tensioning*. These documents, in addition to ASBI and PTI installer certification programs, are major resources for owners that are building and maintaining PT structures.

Figure 6 presents the conditions of the PT tendons investigated by the author grouped by the date of original construction. The vertical axis has been shortened to focus on the upper limits to allow the small quantities to be visible. Even though data in the figure are just for structures inspected by the author, it is evident that the condition of the structures significantly improved over time with refinement of PT systems and procedures, as indicated by the reduced incidence of voids in tendons.

Conclusion

After decades of inspecting PT systems, the author can comfortably assert that, when properly designed, detailed, and installed under the guidelines and procedures published as consensus-based best practices by industry leaders, PT structures are durable, reliable, and cost-effective options for many bridge projects. Within the last 20 years, significant innovations and improvements in PT systems have resolved challenges encountered when the technology was new and spurred growth in the industry. As a result, today's PT systems are designed and constructed to withstand severe conditions.

Bruce Osborn is a field superintendent for Structural Technologies LLC/VSL in Manassas, Va.