lessons learned

Keep Your Strands Dry

Corrosion Protection of Unbonded Post-Tensioning Monostrand Tendons

By Gerard C. Feldmann, P.E.

Do you want to span further, use thinner spans and have virtually crack-free concrete? Sound like hyperbole? Post-tensioned concrete structures have those qualities and have been built for over 50 years in this country with an excellent history. Their construction is nearly identical to conventionally reinforced concrete structures, but some additional measures need to be taken to prevent corrosion of the highly-stressed post-tensioning monostrands and maintain the structures long-term service life.

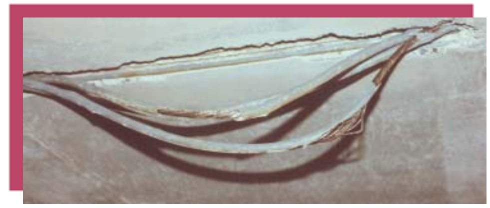

Figure 1: Tendon failure due to corrosion at anchorage

History of Unbonded Tendons in Buildings

A post-tensioned slab building is generally a good choice for a structural system. Why aren't they used more? Most engineers have only a cursory overview of post-tensioning in college, with the main emphasis on conventional reinforced concrete. This unfamiliarity creates a bias towards conventional reinforced concrete structures. Have the engineers heard stories of strands popping out of buildings when the strands fail as shown in *Figure 1*? Does this give post-tensioning bad press? Let's briefly look at the history of unbonded post-tensioned slab construction to show its typical corrosion protection and how it has faired.

Unbonded monostrand tendons were first used in North American buildings in the 1950s with grease coated and paper wrapped ¼-inch button-headed wires. This archaic system had the disadvantage of a non-waterproof sheathing, which would break down with repeated exposure to moisture. The typical post-tensioned monostrand system evolved into single, high-strength seven-wire ½- or 0.6-inch diameter greased strands, sheathed in plastic and anchored with wedges typically in use today.

The evolution of corrosion protection is shown in *Figure 2*. The early systems had sheathing composed of spirally wrapped paper. Plastic sheathing was developed to give the unbonded systems better protection during and after construction. The early plastic sheathing was either a push-through or heat-sealed type, which had an annular space that allowed water to travel if the sheathing or anchorage was compromised. The current extruded plastic sheathing, usually made of polyethylene, is much tighter, leaving very little or no air space in the system.

The last part of the puzzle, and probably the most important, is the grease coating. If the sheathing is damaged and water reaches the strand, the grease can still protect it. Some of the older monostrands actually had grease that would absorb moisture and thus offered little protection when water reached it. The current PTI specification defines the characteristics of the grease coating, such as corrosion inhibiting qualities, compatibility with the sheathing, steel and concrete, cold-weather viscosity, friction and so on.

No standard existed for the various unbonded post-tensioning systems until the 1985 PTI specifications. Each manufacturer theoretically could have its own grease and sheathing type. The current PTI specifications give minimum corrosion protection guidelines for typical installations and modifications for "Aggressive Environments". The corrosion protection of the older monostrand systems was vulnerable at or near the anchorages. Corrosion related failures sometimes allowed the strand to loop out of the slab at high/low spots with little cover, as shown in *Figure 1*. Additional corrosion protection guidelines regarding minimum concrete cover is provided by ACI 318.

Unbonded Strand Tendon Corrosion Protection Evolution and Usual Location for Corrosion (C)

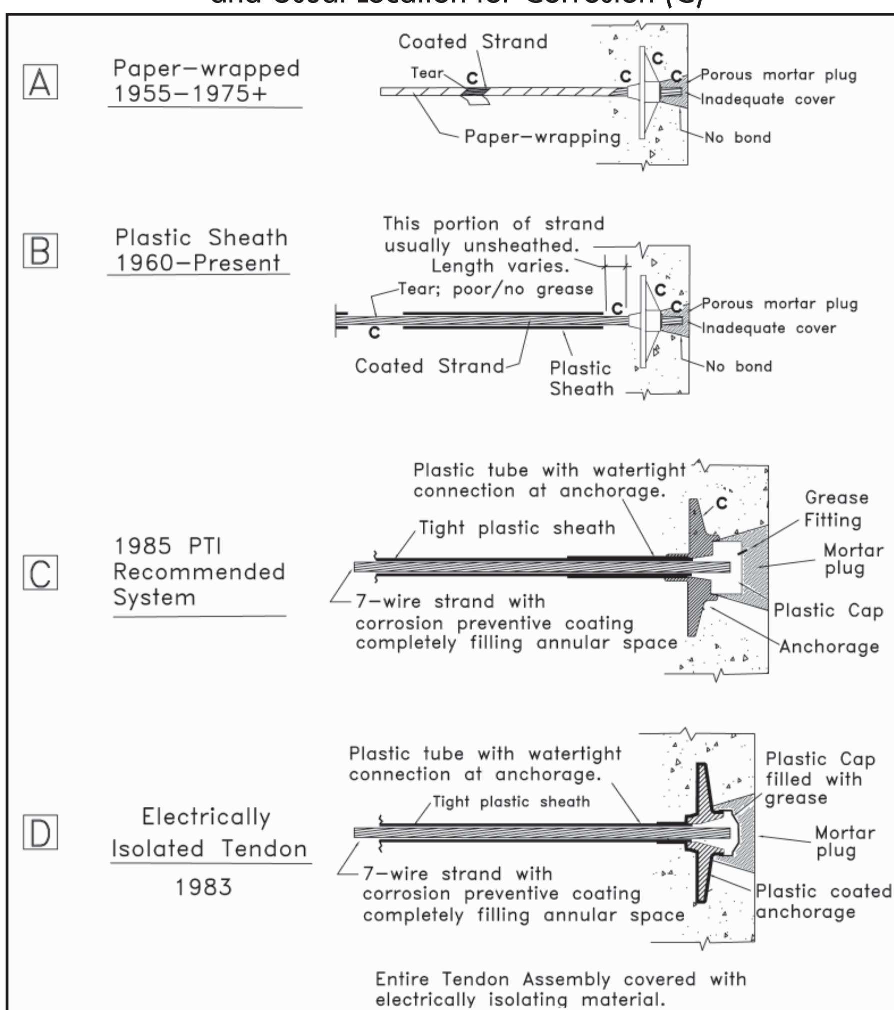

Figure 2: Evolution of unbonded monostrand corrosion protection

Figure 3: Encapsulated monostrand system (Courtesy of GTI)

Monostrand Systems and Performance

The current state-of-the-art corrosion protection is the encapsulated system. This system consists of a typical greased strand with extruded sheathing, with special details at the anchorages. A typical system is shown in *Figure 3*. Watertight connections are made at all sheathing-to-anchorage interfaces, and at the stressing and dead ends. The anchorage casting is covered in plastic. No steel is left exposed. This system is fully electrically isolated from the concrete and other embedded reinforcement. This prevents any corrosion cells to develop. Therefore, no corrosion can occur.

The standard post-tensioning monostrand system for non-aggressive environments contains an extruded plastic-sheathed, grease-coated strand with uncoated anchorages. The stressing pockets do not have grease caps and are filled with mortar. These types of systems have performed well where moisture is not a problem. Most of the problems have occurred at the vulnerable anchorages. *Figure 4* shows possible problems that can occur. It is recommended that even if the overall structure is a non-aggressive environment, some of the anchorage zones could be in an aggressive environment. Examples of this would include buildings with below-grade structural levels, garages and elevated plazas.

The performance of existing buildings with the older monostrand systems is typically very good. The failure rate of monostrands is very low overall. Sometimes a single building or buildings in a city, constructed with similar practices or contractors, could have a large amount of corrosion-related problems. In fact, certain cities in Western Canada actually advertised that buildings were non-post-tensioned because of a rash of well-publicized monostrand corrosion problems. Investigations into these buildings again related most of the corrosion of the post-tensioning to the pre-construction storage and protection of the coiled strands.

Many of the corrosion problems of monostrand systems, both old and new, can be related to the anchorage zones at intermediate and end stressing pockets. The responsibility of cutting the strand extensions and patching the pockets is usually designated to common laborers, who may or may not be aware of the importance of their task. Older monostrand systems that were well constructed usually do not have significant corrosion-related problems.

Examples of Construction Related Problems

Now let's give an example of an actual structure that we recently investigated. The structure is located only 300 feet from the Atlantic Ocean. This prompted the design engineer to specify an encapsulated post-tensioning, which is required for aggressive environments. Everything should have turned out fine. The problem: You have to construct the system according to what was specified. The result for this structure was strand failures only 3 years after construction, with failures continuing to the present day. The investigation concluded that a series of construction miscues occurred due to a lack of understanding by the contractor and limited construction observation by the design professionals. This structure is a good case study in what should not be done.

The specified encapsulated system leaves the full length of the strand protected from the elements but the corrosion of the strand at any location within the stressed region fails the strand.

The problems started before the first slab was even formed up. The contractor stored materials for the site next the building footprint. Now, I like to lie on the sand at the beach, but this is not the place for uncovered monostrands. **Problem 1**: Exposure to rain and possibly salt-spray, as the uncovered strands were only about 250 feet from the surf, resulted in some water entering the strands. The construction of the floors then proceeded. The first slab that was formed up had the strands laid out as per the engineers drawing and, after casting, stressed to the required force. Next, the strand extensions that were used for stressing the monostrands were cut. **Problem 2**: The strands were not cut back far enough to allow the grease caps to be seated properly. The watertightness of the system was compromised. An additional note: This location was at an expansion joint that is not watertight. Water ran down the side face of the slab and into the stressing pockets. One strand failure has initiated here.

Construction continued. Strands were stressed. **Problem 3**: Some strand extensions were not cut back for weeks or months. The current PTI monostrand specification calls for cutting the strand extension and capping the anchorage, in aggressive environments,

continued on next page

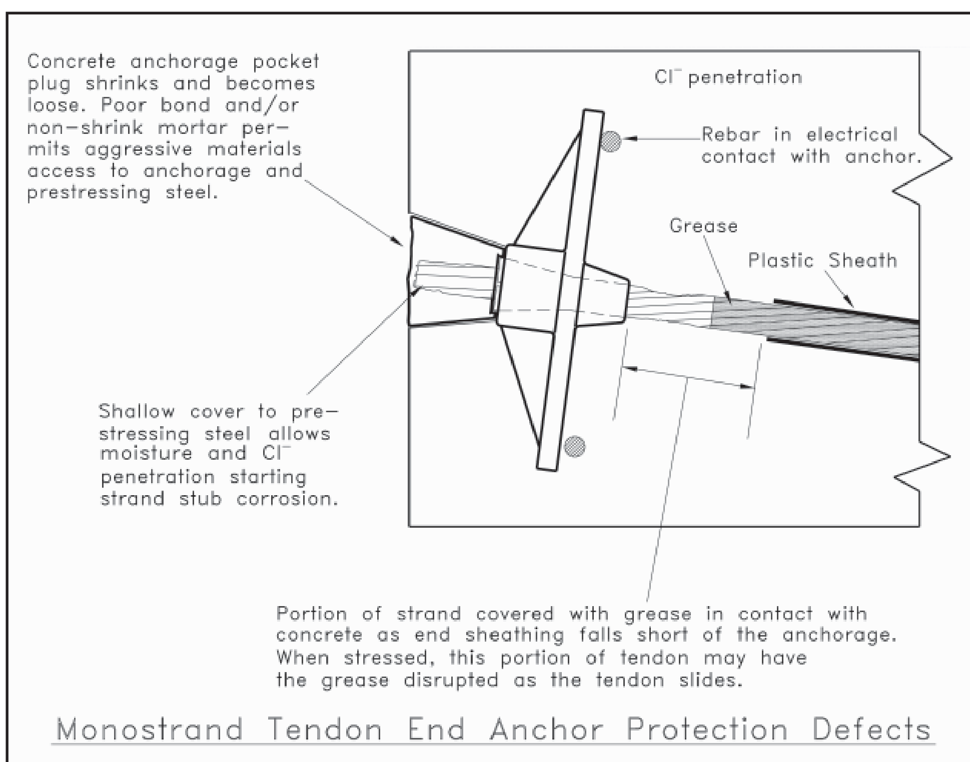

Figure 4: Typical corrosion locations on non-encapsulated monostrands

within 7 days. Additionally, the stressing pocket should be filled with mortar within 10 days following strand cutting. The long delay allowed wind-driven rain to enter the system. In fact, a hurricane occurred during construction, driving water into the structure. If water is driven into the sheathing, it will not leave. It will sit and initiate corrosion until the strand is consumed in the chemical reaction. *Figure 6* is from another structure, but the condition to the referenced building is similar. Here, all of the stressing pockets have been left open in a ten-story building for many weeks, leaving lots of opportunity for moisture to access the anchorage and strands.

Problem 4: The last mistake was a result of the improperly cut strand extensions and the loose grease caps, which meant the stressing pockets could not be filled properly. The ability to pack the stressing pockets with a loose grease pocket left voids at the face of the anchorage, as shown in *Figure 5*, creating another weak link. In fact, in some areas where the stressing pockets were hidden by expansion joints or architectural protrusions, they were left unfilled or filled with fiberglass mesh and stucco. What you can't see can really hurt you, especially the owner's bottom line. Needless to say, millions of dollars have and will be spent to correct the situation. All of it could have been prevented with very little extra cost.

The primary cause of the example problems was a lack of appreciation for the handling and finishing of the encapsulated system. Two years after construction, hotel maintenance people noticed a displaced stressing pocket. The investigation that followed prompted an excavation of the stressing pockets opposite the failed strand. The below-grade stressing pockets were open with no mortar in the pockets. Well, let me correct myself, the pockets were filled, but were filled….with beach sand….without any grease caps! This location and an adjacent group totaling 30 strands were replaced due to heavy corrosion.

Further investigation took random probes at all of the floors. This showed additional corroded/failed strands, as well as unstressed strands. Water was discovered in several of monostrand sheaths. The pattern of failures and corrosion was random in nature. The unknown locations and widespread nature of the construction defects prompted the installation of an acoustical monitoring system that looks at the slabs 24/7. This system uses accelerometers that are sensitive enough to detect the sound of one wire breaking in a seven-wire monostrand. The monitoring over the past two years has yielded signals indicating possible wire breaks. Again, these possible failures have been located randomly in the structure. This monitoring may continue for the life of the structure, unless the rate of corrosion slows to an acceptable level.

Lessons Learned

All the parties involved in the project should be made aware of the importance of the post-tensioning specifications. A pre-construction meeting should include the contractor, post-tensioning supplier/subcontractor, testing lab and engineer of record. All the critical aspects of the post-tensioning should be emphasized. In the example case, responsibilities fell through the cracks. The testing company that observed the strand placement and stressing evidently had only one employee experienced in post-tensioning, but he did not always observe the construction. The field personnel who actually observed the construction were not experienced in the fine points of observing the system. They did not pick up or appreciate the ramifications of the long delay in cutting the strand extensions, the unseated anchorage caps and the filling of the stressing pockets.

The engineer of record should observe the construction process. It has been proven time and again that the owner gets a better-constructed building when the designer takes an active role in the construction observation. Engineers need to explain to the owner that they will be saving potential costs and time delays for the overall project, even with the extra costs related to additional construction observation.

The specifications have to be strictly followed. The post-tensioning specifications were appropriate for the referenced structure, but were not followed to the letter. Remember, the post-tensioning is only as good as its weakest link.

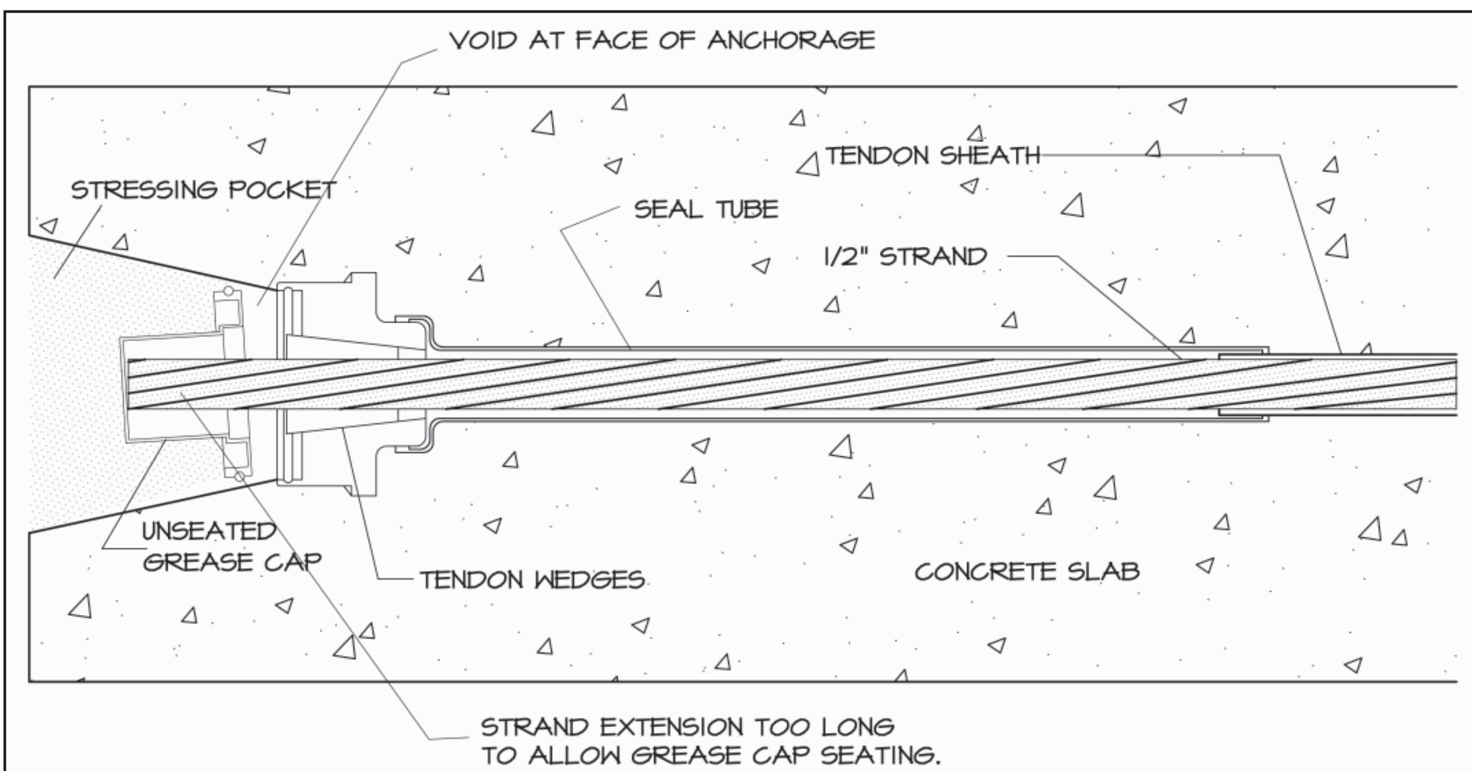

Figure 5: Improperly cut strand extension with resulting mortar void

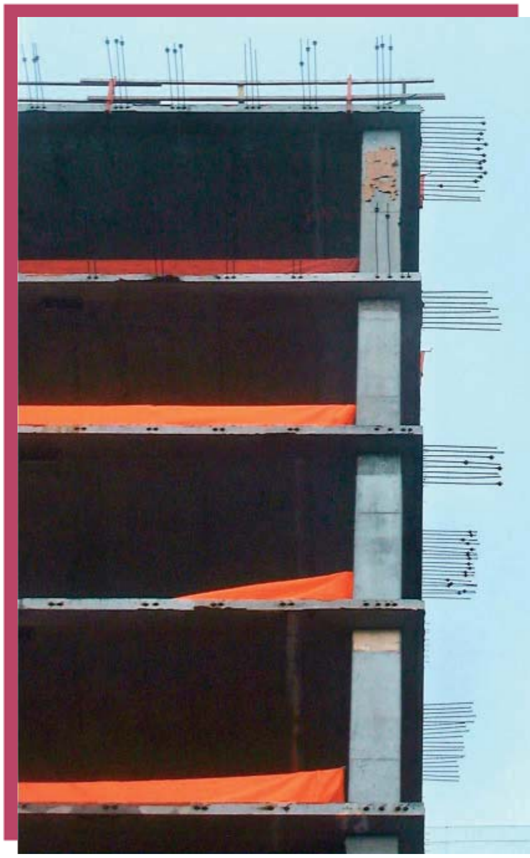

Figure 6: Long term exposure of strand/ anchorages to elements

Conclusions

From field experiences of structures exposed to chlorides in service, it has been found that tendons in the vicinity of a failed corroded tendon was placed with good concrete cover, good anchorage protection and good grease protection had no corrosion problems. Strict compliance with the corrosion protection specifications is required for all tendons in a structure.

It is evident from our experience that corrosion problems are primarily related to poor construction practices, leak-prone sheathing systems and poor end-anchorage protection. The use of the current state-of-the-art encapsulated system gives unbonded post-tensioned structures long durability and excellent long-term performance, for almost no additional costs. This provides their owners one less thing to worry about. *Priceless*.▪

Gerard C. Feldmann, P.E. is a Senior Project Manager and head of the Construction Performance Analysis Group at The Di Salvo Ericson Group in Ridgefield, CT.