PROTECTING UNBONDED PRESTRESSED TENDONS

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INTRODUCTION

As the demand for parking garages increased in North America over the last 50-plus years, there has been an increased use of unbonded prestressing tendons. The efficiency of these systems provides the designer with the necessary tools to span long distances with relatively shallow beams and/or slabs.

Unbonded prestressing tendons have gone through an evolutionary process during their history. The original prestressing tendons were button-headed wires that were coated with grease and then wrapped in paper to prevent bonding to the concrete and to provide protection against corrosion. Following that system was the seven-wire wedge system with the strand coated with grease and wrapped with paper. Following the paper wrap process were three different processes using plastic sheathing: (1) the push-through system, which then had grease injected into the plastic duct; (2) the strand was wrapped with a heat-sealed plastic and grease was injected at the extruder; and (3) the greased strand was covered with a molten plastic that was continuously extruded around it. The push-through system was the system of choice in Canada, whereas the other systems were more popular in the U.S.

Two problems that have arisen are the corrosion of the end anchorages and corrosion of the tendon strands that result from the infiltration of moisture within the tendon's sheathing. The early grease systems did not stand up well to the aggressive environment in parking garages. Most of these greases will dry out with time or will emulsify in the presence of moisture. As the greases dry out or emulsify, the tendon strands that are exposed to moisture have a tendency to corrode.

The protection of the prestressed tendons is critical to the long-term life expectancy of any building structure; however, parking garages are extremely vulnerable to deterioration and subsequent failure because they are exposed to the elements, as well as salts and other deleterious materials. To assure the lowest cost/benefit ratio and to maximize the structure's life expectancy, an effective protection system that includes regular inspections, repair, and protection of the prestressed tendons should be implemented. The time line from construction to the initiation of a maintenance program will vary depending on the design, construction, and environmental exposure.

To address the corrosion problem and provide the protection necessary to assure the long-term serviceability of the unbonded tendon strands, there is a proprietary system known as the Jamor P/T Grouting System,* which is currently in use in North America.

PROBLEM

The installed tendons are subject to accelerated corrosion when moisture is permitted to access the end anchorages and/or penetrate the sheathing that has been designed to keep moisture from accessing the tendon. This problem can occur for any one or more of the following reasons:

1. Moisture is permitted to penetrate the sheathing prior to encapsulation of the tendon with concrete;

2. Moisture is permitted to penetrate the sheathing through cuts in the sheathing that occur during handling and/or placement of the concrete;

3. Moisture is allowed to penetrate the sheathing that has been violated due to abrasion at the surface of the concrete due to lack of cover;

4. Moisture is permitted to penetrate the sheathing through cracks in the concrete at points where cuts in the sheathing occur; and

5. Moisture is permitted to penetrate the sheathing through the end anchorages. The moisture penetration problem is aggravated if the moisture should contain chlorides such as deicing salts, seawater, or spray from these sources.

*US Patent No. 5,540,030 and Canadian Patent No. 2,137,051.

Fig. 1—Corroded strand at surface.

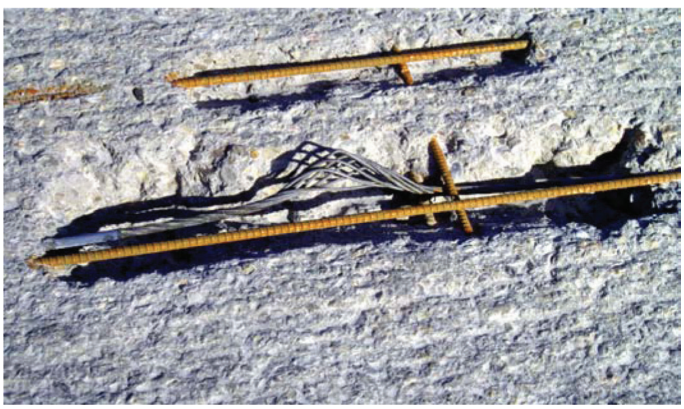

Fig. 2—Result of broken strand.

Fig. 3—Modified coupler attached to tendon end with stressing jacks.

If left unchecked, the corrosion process will cause failure of the prestressed tendons (Fig. 1 and 2). Each tendon is made up of seven wire strands. The corrosion process reduces the cross-sectional area of the strand(s), thereby reducing the load-carrying capability of the tendon. The time to failure will depend on the level of stress that has been induced in the tendon at the time of prestressing and the corrosion rate. Once a tendon has failed, it must be replaced or spliced, then restressed to reestablish the original structural integrity of the beam or slab.

Then, the nagging question that plagues the owners of the structure is “How many more tendons are about to fail?” “How can I prevent any future failures?” These questions must be answered if the owner is to optimize the life-cycle cost of the structure.

INSPECTION AND EVALUATION OF PRESTRESSED UNBONDED TENDONS

The evaluation of prestressed unbonded tendons for corrosion can be accomplished visually for short distances only by exposing the tendons, usually at the high or low points of the tendon’s drape. Although moisture is most likely to be present at the low points, the presence of moisture does not automatically mean that corrosion has started, nor does the absence of moisture mean that there is no corrosion present in the tendon. This inspection procedure only provides confirmation of corrosion in the exposed section.

In the absence of any test procedure that accurately determines the presence, degree, or location of corrosion outside the area of visual inspection, the evaluation of the unbonded tendons is commonly limited to determining if the tendons are under tension and if the tendons are capable of carrying the tensile force they have been designed to carry.

Evaluation of the in-place tendon performance capability can be performed by attaching a modified coupler and stressing jack to the exposed tendon end (a minimum exposed length of 5/8 in. is required) and apply a tensile force sufficient to loosen the wedges (Fig. 3). This procedure usually does not exceed the original tensile force required to set the wedges. Occasionally, this procedure will induce a failure of the tendon. The tendon is then normally removed and inspected to determine the extent of damage at the point of the break.

When access to the tendon ends is not possible or there is insufficient tendon length to attach a modified coupler, another type of evaluation technique should be performed. This can be achieved by exposing the tendons to a visual inspection at the high or low points. The low point is usually the best option to minimize the exposure of the tendons to the top surface abuses and to determine if water is present in the sheathing at the point of exposure.

To determine if the tendon is under tension, equipment evaluating the vibration characteristics of the strand under tension can be used. Approximately 2 ft of the strand should be exposed, chocks should be installed at each end of the exposed section to provide node points, an accelerometer should be installed on the strand, and vibration should be induced in the strand by tapping. The vibration is measured by the accelerometer and transferred to a computer to determine the tension in the strands as a function of the frequency of the vibration.

The presence of tension in the strand can also be determined with a blunt-ended tool, such as a screwdriver. Approximately 1 ft of strand should be exposed. The tool should be covered with plastic and inserted between the strands to determine whether they are loose or taut. Care must be taken not to damage the strands and risk a failure of the tendon.

Tendons that have failed must be repaired or replaced. There are generally two types of repairs. The most common failure of the tendon will usually occur at some point within the tendon length—usually at the high or low point. This type of failure commonly occurs from corrosion. If there is no other problem, the tendon may be repaired by splicing and then restressing. This procedure has a risk because there may be corrosion at another undetermined point that may fail during the restressing operation.

The second type of break may occur in the tendon at the bulkhead. This type of failure commonly occurs when the anchorage is exposed to an aggressive environment and the anchorage was not protected at the time of construction. A new bulkhead can be established within approximately 4 in. (100 mm) of the end of the failed tendon end. This can usually occur 9 to 18 in. (200 to 450 mm) from the original bulkhead, depending on the original elongation of the stressed tendon. The tendon would then be restressed.

The alternative is to replace the tendon and then restress. The tendon may be replaced with the same size or smaller tendon. The same-size tendon replacement has been successfully accomplished up to 200 ft (60 m) in a "push-through preformed tube" and 125 ft (38 m) in an extruded sealed system. This procedure may require replacement with a smaller tendon and, subsequently, reduced load capacity.

PROTECTION OF UNBONDED TENDONS

Unbonded tendons are shipped from the factory covered with grease and encased in a protective sheathing. Following installation of the tendons at the construction site, the sheathing is subject to abuse during the placement of the portland cement concrete.

Following the placement and subsequent curing of the concrete, the tendons are then stressed to a predetermined level. This operation exposes a section of unprotected tendon at the bulkhead. As the grease dries and/or emulsifies, the tendon becomes exposed and the void system further increases in size and thereby produces a larger cavity capable of more easily holding air and water.

Water can easily penetrate the tendon's protective sheathing under a variety of different conditions. The resulting action can be emulsification of the grease and subsequent corrosion. The corrosion process is further accelerated if salt is present in the water. Because it takes a lot more time for the water to evaporate than it does to penetrate, the sheathing corrosion is inevitable. Only the time to failure is uncertain.

Although corrosion is occurring, it cannot be detected with nondestructive testing techniques. The ultimate consequence of prestressed tendon corrosion is tendon failure. The evolution of polymeric materials has provided us with polyurethane that has the physical and mechanical properties that will provide long-term protection to a prestressed tendon.

THE POLYMER

A two-component polyurethane resin has been developed for grouting unbonded post-tensioned cables. The polyurethane grouting system must have physical and mechanical properties that have the capability of penetrating the full length of the unbonded tendon sheathing and then protecting the strand of the tendon against corrosion. The polyurethane will fill the void system within the sheathing and prevent the infiltration of water that would otherwise provide the vehicle for corrosion.

The polyurethane must have physical properties that will permit the system to flow through the void system within the tendon sheathing—under pressure—for distances as great as 200 ft. The pot life must be sufficient to allow the polyurethane to retain its flow properties over the period of the injection process.

The polyurethane material that is currently being used in the Jamor P/T Grouting System* is identified as PTG-104 and has the following physical properties:

Viscosity	200 cps
Pot life (100 gms)	2 hours

Fig. 4—Pumping urethane into sheathed tendons with multiple-component pump.

Fig. 5—Cured polyurethane encapsulating prestressed tendon within sheathing.

A physical property that has a major influence on the polyurethane's ability to flow through the small void system is its surface tension. The surface tension of polymers affects their ability to wet the substrate material and flow through very narrow voids. To achieve this, the surface tension should be as low as possible. In the absence of data defining a material's surface tension, the performance capability must be determined by field testing and evaluation.

Although research reports presented at RILEM conferences have alluded to the benefits of knowing a polymer material's surface tension property, the research community has not recognized the value of this information and, subsequently, material suppliers are not currently providing this information. In its absence, epoxies and polyurethanes used to fill cracks and other small voids cannot be determined as equal, based on the mechanical and physical properties reported by the material suppliers and required by ASTM International. The suitability of a material for any given condition is often in the hands of people who have tested the performance of these materials under similar conditions. Their experiences may likely determine the success or failure of an injection process.

In addition, the polyurethane system must be hydrophobic to assure its ability to displace water that is trapped within the tendon's sheathing. This process would not be effective if the polyurethane is hydrophilic because the material would produce foam upon contact with the water. This would produce a barrier to the flow of the polyurethane within the tendon sheathing.

The mechanical properties of the urethane will determine its ability to provide the necessary long-term protection of the unbonded tendon. To achieve long-term protection, the urethane must be capable of encasing the tendon and the individual strands. To resist the flexing action of the structural component as the live loads are applied, the polyurethane must be flexible and at the same time have the hardness to resist the pressure that it will be subjected to. Mechanical properties that have been found to work and reflect the properties of PTG-104 are:

Elongation	ASTM D638	185%
Shore hardness	A scale	30
Water absorption	ASTM D570	<1%

THE SOLUTION

To provide the necessary solution requires replacement of the original protective grease that has since dissipated. To achieve this, the void system left by the dissipated grease must be replaced by a polyurethane grout that will encapsulate the steel wires and protect them from moisture and oxygen.

The polyurethane grout will be injected into the void space around the tendons by a high-pressure multiple component pump (Fig. 4). The pump will push each of the two components through a mixing head that will uniformly mix the components into a homogenous solution. The pump then should have the capability to pump the mixed solution a distance of up to 120 ft. Most applications will require a pumping distance of 60 ft or less.

The point of access may be at the end of the prestressed tendons, but most likely at an intervening point in which the tendon is at a high or low point.

The injection process will be applied to all the tendons in a bundle at the same time. This provides an increased level of efficiency and minimizes the chance of the polyurethane grout exiting one encapsulated tendon and entering another in midstream. This problem has occurred when two tendons running adjacent to each other and in contact with one another coincidentally have a break at the same point. The contractor then has a false impression of the success of the injection process.

CONCLUSIONS

There will be more than one polyurethane that meets the mechanical properties necessary to protect the unbonded tendons; but if the installation cannot be accomplished due to inadequate physical properties, then the material will fail to perform to the client's satisfaction. Material installations that are not satisfactory often cannot be visually confirmed and their deficiencies may not be discovered for several years. The problem may be further compounded when the engineer assumes a satisfactory installation is accomplished because some predetermined procedure is followed.

We are able to solve problems in maintaining our infrastructure by learning more about the available polymers and their properties that can be used to achieve long-term protection of the post-tensioning systems. The product selection process is based primarily on the mechanical properties of the material because they are essential to the long-term performance. The physical properties, however, are essential to the material installation or application process and must be given equal consideration.

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