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Corrosion and Repair of Grouted Post-Tensioning Tendon Systems—Report

Reported by Joint ACI-ASCE Committee 423

ACI PRC-423.8-21



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Corrosion and Repair of Grouted Post-Tensioning Tendon Systems—Report

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Corrosion and Repair of Grouted Post-Tensioning Tendon Systems—Report

Reported by Joint ACI-ASCE Committee 423

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This report provides general information regarding the evaluation of corrosion damage in structures reinforced with grouted multi-strand and bar tendons. A review of current practice is included along with the historical background. Specific potential problem areas for grouted tendons are discussed for each critical part of the tendon. Current methods for evaluating corrosion damage and typical repair schemes are included.

Keywords: anchorage; bonded; corrosion; duct; durability; grout; post-tensioning; prestressed; repair; strand; tendon.

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ACI PRC-423.8-21 supersedes ACI 423.8R-10, was adopted July 19, 2021, and was published November 2021.

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CHAPTER 1—INTRODUCTION

1.1—Introduction

The use of grouted high-strength wire, strand, and bar post-tensioning tendons as a viable construction technique began in North America in the 1950s ([Post-Tensioning Institute 2006](#)). Components of the standard system have changed significantly from shimmed button-head wire-type systems to bundles of seven-wire strand systems with wedges. Post-tensioning bars may also be used in grouted systems, although they have not changed significantly since their first introduction. The latest generation of post-tensioning systems include multiple layers of corrosion protection due to an increased awareness of the susceptibility of earlier systems to corrosion and the importance of a durable system.

Grout material is used in post-tensioning tendons to fill the voids in the ducts, to provide bond between the tendons and the structural element, and to provide corrosion protection for the tendons. Historically, grout consisted of a standard mixture of water and portland cement; sometimes, however, chemical admixtures were included to increase pumpability, to introduce expansion in an attempt to counteract settlement and voids, or to reduce bleeding. In the late 1990s, the discovery of tendon corrosion in several post-tensioned bridges in Florida ([Corven Engineering, Inc. 2001](#)) prompted a change in grouting materials, including the introduction of prepackaged grout formulations containing anti-bleed admixtures. Past performance of grouted post-tensioning systems is covered in more detail in [4.1](#).

The discovery of corrosion problems has also led to the development of various methods for the evaluation and repair of corrosion damage to grouted tendon systems ([Hurlebaus et al. 2016](#)). Over the past two decades, many bridges have undergone evaluation and repairs, if required ([Schokker and Berg 2012](#); [Sprinkel and Balakumaran 2017](#)).

Evaluation methods vary; however, most include nondestructive methods as well as exploratory evaluation for detection of voids, water, or soft grout within the ducts and corrosion of the prestressing steel. Repairs typically consist of removal of water and soft grout followed by filling the voided space within the ducts with grout. If a tendon has lost significant cross section due to corrosion, the tendon may need to be replaced. [Chapters 5 and 6](#) cover evaluation and repair methods in greater detail.

1.2—Scope

This report includes a review and summary of the following:

- (a) Guide specifications and training as applied to grouted post-tensioning tendons
- (b) Quality control during construction
- (c) Potential problem areas in grouted systems
- (d) Durability enhancements for each component of the tendon
- (e) Evaluation and mitigation of corrosion problems
- (f) Repair methods for grouted systems

This report is intended to provide general information on the corrosion and repair of grouted multistrand and bar tendon systems. The information is intended to represent the state of knowledge of the committee in the areas of corrosion prevention in grouted tendons, as well as evaluation and repair. It is not intended as a standard or recommended practice. A strong background in durability of grouted post-tensioning systems, including practical experience and training, is recommended before designing, constructing, evaluating, or repairing these structures.

This report focuses on the unique materials and hardware associated with grouted post-tensioning tendons with a discussion of efforts within the industry to improve durability. This report also provides recent practice with regard to evaluation and repair of grouted post-tensioning systems. General corrosion theory for metals in structural concrete systems is not within the scope of this report. Information on corrosion theory and mechanisms can be found in [ACI 222R](#) and [ACI 222.2R](#). Information on inspection and evaluation of unbonded single-strand post-tensioning systems can be found in [PTI DC80.3/ICRI 320.6](#).

1.3—Limitations

This report presents a summary of the typical corrosion-related problems that may occur in grouted post-tensioning systems and includes guidelines for evaluation and repair. The material is general in nature and may not apply to every situation. Due to the uniqueness of each post-tensioned structure, engineering judgment should be used to determine the appropriate action based on experience and the general guidance provided in this document.

This report is not intended to be included as part of a specification document for materials, evaluations, or repairs. Evaluation of grouted post-tensioning tendons is a difficult undertaking, and no single method can be used to fully describe the damage or life expectancy of a tendon. Due to the many changes in material and equipment since the

1950s, the investigator may encounter wide variation in the types of systems. Varying climates, environments, and the structure's usage and design also play a role in possible deterioration. Given these complexities, the investigator should have knowledge of the performance of similar structures in similar environments, and they should have experience in the evaluation and repair of these systems.

CHAPTER 2—DEFINITIONS

Please refer to the latest version of ACI Concrete Terminology for a comprehensive list of definitions. Definitions provided herein complement that resource.

admixture—a material other than water, aggregates, cementitious materials, and fiber reinforcement, used as an ingredient in a cementitious mixture to modify its freshly mixed, setting, or hardened properties and that is added to the batch before or during its mixing.

backflow—a condition whereby the grout front reverses direction and flows back on top of the grout layer in the bottom of the duct.

bleed—the autogenous flow of mixing water within, or its emergence from, a newly placed cementitious mixture caused by the settlement of solid materials within the mass and filtering action of strands and wires; pressure increases the propensity of a grout to bleed.

cementitious materials—materials having cementing properties.

corrosion inhibitor—a chemical compound, either liquid or powder, usually intermixed in concrete and sometimes applied to concrete, and that effectively decreases corrosion of steel reinforcement.

duct—a conduit (plain or corrugated) to accommodate prestressing steel for post-tensioned concrete.

fluidity—a measure of time, expressed in seconds, necessary for a stated quantity of grout to pass through the orifice of the flow cone.

grout—a mixture of cementitious material and water, with or without aggregate, and with or without admixtures; injected into the duct to fill the space around the tendon.

high-range water-reducing admixture—see **water-reducing admixture**.

inlet—tubing or duct used for injection of grout into duct; includes a positive shutoff.

outlet—tubing or duct to allow the escape of air, water, grout, and bleed water from the duct; includes a positive shutoff.

post-tensioning—method of prestressing in which prestressing steel is tensioned after concrete has hardened.

prestressing steel—high-strength steel used to prestress concrete, commonly seven-wire strands, single wires, bars, rods, or groups of wires or strands.

segregation—(1) nonuniform concentration of components in concrete or mortar; (2) nonuniform distribution of size fractions in a mass of aggregate; (3) the gravitational settlement of solids from a liquid (also called “separation”).

set—the condition reached by a cement paste, mortar, or concrete when it has lost plasticity to an arbitrary degree, usually measured in terms of resistance to penetration or

deformation; “initial set” refers to first stiffening; “final set” refers to attainment of significant rigidity; also, strain remaining after removal of stress.

set time—the lapsed time from the addition of mixing water to a cementitious mixture until the mixture reaches a specified degree of rigidity as measured by a specific procedure.

soft grout—grout that has not hardened due to lack of reactive cementitious materials and excess water due to segregation.

tendon—an assembly consisting of a tensioned element (such as a wire, bar, rod, strand, or a bundle of these elements) used to impart compressive stress in concrete, along with any associated components used to enclose and anchor the tensioned element.

thixotropic—a reversible, time-dependent decrease in viscosity when a fluid is subjected to increased shear stress or shear rate.

vacuum grouting—a process by which a partial vacuum is generated within a void to create a pressure differential that allows grout to flow into and substantially fill the void through a single grout inlet.

volume change—an increase or decrease in volume due to any cause.

water-reducing admixture—an admixture that either increases slump of freshly mixed mortar or concrete without increasing water content, or maintains slump with a reduced amount of water, the effect being due to factors other than air entrainment.

wet density—the unit weight of grout in its plastic state.

CHAPTER 3—REVIEW OF CURRENT PRACTICE

3.1—General

Code requirements regarding post-tensioning durability were minimal prior to publication of the Post-Tensioning Institute's (PTI) “Specification for Grouting of Post-Tensioned Structures” in 2001 (the current edition as of publication of this guide is **PTI M55.1-19**). This comprehensive document focuses on grouting, including materials, construction, and testing, with emphasis on new construction.

The American Segmental Bridge Institute (ASBI) established a Grouting Certification Program in 2001, which provides training and background on successful grouting of post-tensioning tendons and culminates in a certification exam. Grouting best practices taught at this course follow PTI M55.1.

Certain state departments of transportation (DOTs) have developed their own detailed specifications for durability of post-tensioned bridges. The Florida Department of Transportation (FDOT), for example, maintains a comprehensive state specification (**FDOT 2007**).

3.2—Grouting requirements

The PTI M55.1 specification is divided into four main sections: materials, design, testing, and construction. This specification should be consulted for a full description of requirements in each area. Basic concepts are outlined in 3.2.1 through 3.2.4.

3.2.1 Materials—Grout consists of portland cement and water and may also include chemical or mineral admixtures as well as fine sand. Pozzolans used in concrete may also be used in grout. Silica fume and fly ash, both Class C and Class F, are the most commonly used. Because fly ash may vary considerably from different sources, a consistent source should be used to achieve similar field properties to the ones found during mixture development in the lab. Fly ash can potentially reduce bleed, increase workability, and reduce permeability. Silica fume has been shown to improve corrosion protection in concrete by reducing the permeability of the concrete. In grouts, however, the particles may agglomerate. Testing has shown better performance with inter-ground silica fume cements (Brooks 2003).

Chemical admixtures used in grout have included high-range water-reducing admixtures (HRWRAs), anti-bleed admixtures, expansive admixtures, and corrosion inhibitors. HRWRAs help achieve workability at low water-cementitious material ratios (w/cm). For constant water content, adding only water reducers or HRWRA usually increases bleed, so the admixture should not be added beyond the mixture design amount.

High-performance grouts typically have thixotropic properties. When thixotropic grouts are agitated, this leads to a reduction of yield stress, enabling ease of pumping but they will stiffen and appear gel-like at rest (Fig. 3.2.1).

Anti-bleed admixtures, also called gelling agents or stabilizers, are necessary for applications requiring strong bleed resistance or water retention in grout. Silica fume and fly ash mildly improve bleed resistance but are not adequate alone for the high water-retentive properties needed for many applications. Bleed in grouts is discussed in 4.3.

Expansive agents have been used in grouts for many years with the premise of counteracting bleed and voids with expansion of the grout. A small amount of expansion to offset settlement may be desirable, but the use of aluminum powder and other gas-forming expansion admixtures should be avoided. These admixtures may have widely varying levels of expansion when combined with different cements. They also may cause an interconnected air-void system, leading to higher permeability. The perceived benefit of

counteracting bleeding does not occur because bleeding continues until the grout is set.

Corrosion inhibitors have not been shown to be an effective solution for reducing corrosion in post-tensioning (PT) grouts. Accelerated testing has indicated a potential reduction in corrosion protection (Pacheco et al. 2007). A well-designed anti-bleed grout with low water content is recommended over the addition of corrosion inhibitors in grout (PTI M55.1).

For any grout design, care should be taken to use consistent materials between laboratory testing, mixture development, and field mixing. Materials should be stored per manufacturer's directions, including attention to expiration dates.

3.2.2 Design—Chapter 3 of PTI M55.1-19 provides performance requirements for grouts divided by classes. Class A grouts are for nonaggressive exposure applications, Class B grouts are for aggressive exposure applications, Class C grouts are prepackaged grouts suitable for aggressive environments, and Class D grouts are for special applications. PTI M55.1 provides performance requirements for each grout class.

3.2.3 Testing—Laboratory testing should be performed at a constant water content for a given grout design. Prepackaged materials should state a maximum and minimum w/cm on the bag, and laboratory testing should be performed at both water contents. Property testing includes set time, strength, permeability, volume change, fluidity, bleed resistance, corrosion resistance, and wet density. Fluidity testing gives an indication of the pumpability of the grout. A flow cone test is used to estimate fluidity. A modification is made for thixotropic grouts because these grouts require additional energy to flow. Bleed testing includes a wick-induced bleed test that indicates a grout's ability to resist the filtering effects of the strand in low-vertical-rise bleed situations. For more severe bleed situations, refer to ASTM C1741. This test requires pressurization of a cylinder of grout against a filter to separate the water. Various pressure levels are used to give an indication of the grout's bleed resistance at different vertical heights (columns of grout). Field testing may include fluidity, wet density, sampling for strength, and bleed resistance. Field mockup tests may be required by the engineer.

3.2.4 Construction—The construction section of PTI M55.1-19 covers material storage, preparation for grouting, the grouting operation, and post-grouting procedures. Chapter 4 of this report reviews post-tensioning materials and construction practices related to grouting.

3.3—Tendon protection requirements

Specific tendon protection requirements for grouted post-tensioning structures can be found in PTI M50.3. The PTI specification sets forth post-tensioning system tendon protection levels (PLs) depending on exposure conditions and project needs, and includes requirements for ducts, grout, and system components. Protection Level 1A (PL1A) permits the use of basic cement-water grout and galvanized ducts, and is intended for structures that are not subject to aggressive exposures (for example, an enclosed building).

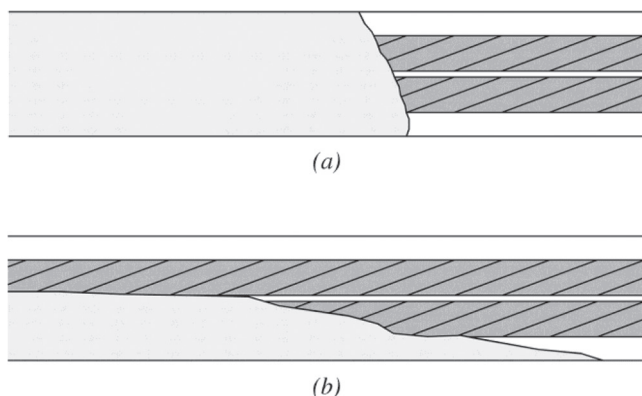


Fig. 3.2.1—Typical flow patterns for: (a) thixotropic grout in high-viscosity state; and (b) plain water-cement grout (Schokker et al. 2002).