

Post-Tensioning Tendons: Grout, Corrosion and Inspection

Bonded post-tensioning carries much of the load in segmental box girders, spliced girders, cast-in-place box girders and PT substructures. The tendons are hidden inside ducts, so the steel is protected only by the grout, the duct and the concrete around them, and failures are usually found late. This course follows two public FHWA sources. The first is the Post-Tensioning Tendon Installation and Grouting Manual, FHWA-NHI-13-026 (Corven and Moreton, Version 2.0, May 2013), which covers components, grout materials, grouting practice and corrosion protection. The second is Guidelines for Sampling, Assessing, and Restoring Defective Grout in Prestressed Concrete Bridge Post-Tensioning Ducts, FHWA-HRT-13-028 (Theryo, Hartt and Paczkowski, October 2013, with the January 2014 errata), which covers inspecting tendons in existing bridges, grout sampling, grading and restoration. Code and specification references are quoted as these sources state them; confirm against current editions. Worked numbers are labeled illustrative.

Learning objectives

- Describe PT system components
- Explain grout voids and segregation
- Identify tendon inspection methods
- Apply lessons from tendon failures

Why post-tensioning tendons need special attention

Concrete is strong in compression and weak in tension. The FHWA manual puts its tensile strength at only about 10 percent of its compressive strength. Post-tensioning solves this by stressing high-strength steel after the concrete has hardened and locking that force into the structure at the anchorages. The concrete is placed into compression, and service tension is cancelled or reduced.

In a bonded system the tendon runs inside a duct that is filled with cementitious grout after stressing. The grout has two jobs. It bonds the strand to the structure, so the tendon acts with the concrete at strength, and it protects the steel. Grout is alkaline, and steel in an alkaline environment forms a passive film that keeps the corrosion rate negligible. FHWA-HRT-13-028 describes this as a pH above 13 maintained in contact with the strand.

That protection is invisible. An inspector walking a box girder sees the concrete, the ducts of any external tendons, the anchor blisters and the pour-backs. The strand itself is visible only where someone has opened a grout cap or cut a window in a duct. A void at a high point, bleed water trapped at an anchorage, or a pocket of soft segregated grout can sit for years before anything shows on the surface. When it does show, it can show as a failed tendon.

This matters because a tendon is a concentrated element. A single 19-strand tendon may carry a large share of a web's prestress. Losing one strand is a small fraction; losing a whole tendon in a span designed with a handful of them is a significant event. FHWA-HRT-13-028 records that durability concerns came to the forefront in 1999, when engineers became aware of failures from grout voids, bleed water and strand corrosion at high points such as anchorages and crests. By the time that report was written, 10 States had reported tendon problems stemming from grout deficiencies or excessive chlorides.

The course covers four objectives:

- Describe the components of a PT system: strand and bar, anchorages, ducts, inlets and outlets, grout caps and grout.
- Explain how grout voids, bleed and segregation form, and why they lead to corrosion.
- Identify inspection methods for tendons in existing bridges, from visual walk-throughs to drilling, borescopes, grout sampling and the limits of NDT.
- Apply the lessons from tendon failures to inspection, grading, restoration and new construction.

Related LoadPath PDH courses include BR-P01 and BR-P02 on prestressed concrete, BR-C01 and BR-C02 on concrete deterioration and repair, and BR-I01 on inspection fundamentals.

Tendon components: strand, bar and anchorages

Prestressing strand. The manual describes seven-wire Grade 270 low-relaxation strand to ASTM A416 as the usual tendon material. Common sizes are 0.5 in. strand, with an area of 0.153 in², and 0.6 in. strand, with an area of 0.217 in²; the manual notes 0.62 in. strand is increasingly used. Breaking strength is expressed as the minimum ultimate tensile strength (MUTS), the minimum specified breaking force. Acceptance testing uses three 5 ft samples from each lot, and the samples must reach 100 percent of the specified ultimate strength.

The manual describes strand as relatively resistant to stress corrosion and hydrogen embrittlement, but warns that susceptibility to corrosion rises with strength. Epoxy-coated strand is covered by ASTM A882. Fatigue is not generally significant for bonded tendons, the manual says, except in stay cables.

Bars. PT bars are typically 150 ksi steel to ASTM A722 Type II, commonly 1-1/4 to 1-3/8 in. diameter. Bars anchor with spherical nuts bearing on plates. Bars used for temporary stressing, for example in segmental erection, should be kept at or below 50 percent of their ultimate strength so they can be reused.

Anchorages. FHWA-HRT-13-028 notes that anchorage systems are proprietary. Systems by VSL, Dywidag (DSI), Freyssinet, BBR and Schwager Davis are found in U.S. bridges. A basic anchorage has a bearing plate, a trumpet that transitions from the duct to the plate, a wedge plate (anchor head) holding the strands with wedges, a grout cap and grout ports. Shapes and port orientations differ by system, which matters later: before drilling through a grout port to look inside a trumpet, the inspector must know which system is installed. The guideline's advice is to find the PT shop drawings, which show the system details.

After stressing, the strand tails beyond the wedges are cut. The manual says this should be done with an abrasive disc or plasma cutter; flame cutting should not be used.

Grout caps. The manual describes permanent grout caps of an inert material, approved plastic, galvanized metal or stainless steel, as significant protection for the wedge plate, wedges and strand tails, or a bar nut. The cap fills with grout during tendon grouting, through a hole in the wedge plate and the gaps between wedges and strands, and needs a vent at its top so it fills completely. It must be sealed and secured to the anchor plate.

Ducts, inlets, outlets and couplers

The duct forms the void that the tendon occupies, and in the protection hierarchy it is the barrier between the grout and the outside world. The manual's requirements include:

- **Size.** AASHTO LRFD 5.4.6.2, as quoted, requires the duct area to be at least 2.0 times the net strand area, or 2.5 times where strands are pulled through after concreting. PTI/ASBI M50.3-12 sets 2.5 times. Flat ducts are limited to four 0.6 in. strands, with clear inside dimensions of at least 1 in. by 3 in. Bar ducts need at least 1/2 in. clearance around the bar.

- **Material.** Corrugated galvanized steel ducts are 26 gauge below 2-5/8 in. diameter and 24 gauge above, with a G90 zinc coating. Rigid steel pipe is ASTM A53 Schedule 40. Polyethylene (HDPE) ducts are black for ultraviolet protection.
- **Inlets and outlets.** At least 3/4 in. diameter, or 3/8 in. for bars and for tendons of four strands or fewer. Outlets are placed at high points and anchorages so air and bleed can escape.
- **Couplers and joints.** In precast segmental construction, ducts cross match-cast joints through couplers so the joint epoxy does not form the only seal. The manual says duct tape should not be used to seal duct connections.

Each of these details is a lesson. The corrosion chapter lists seam leaks in galvanized ducts, split polyethylene ducts, and holes punched with a hammer and nail to vent a duct and then left unrepaired. Every one of those creates a path for water, air and chlorides to reach the grout.

Internal and external tendons. Internal tendons run in ducts cast inside the concrete, so the concrete is an extra barrier but the tendon cannot be seen. External tendons run inside a box girder cell in polyethylene ducts, passing through deviators and anchored in diaphragms. They can be seen and reached along their length, but the duct is their only physical barrier between the deviators and anchorages, and the deviator and diaphragm regions are embedded and hidden. Most span-by-span segmental bridges use external tendons; balanced cantilever bridges use internal cantilever tendons in the top slab and continuity tendons in the bottom slab, often anchored in blisters.

Grout: what good grout must do

The manual sets out what modern PT grout must achieve and how it is tested. Grout is classified in PTI M55.1-12 into Classes A through D by exposure. Key points the manual makes:

- The water to cementitious materials ratio is limited to 0.45, and water must never be added on site to improve flow.
- On-site mixing of plain cement grout with high-range water reducer is not recommended. Pre-bagged, pre-qualified grouts are available, including thixotropic grouts that are fluid while being pumped and stiffen at rest.
- Laboratory trials should be done at least 8 weeks before grouting.
- Fluidity is checked by flow cone. The efflux time must stay under 30 seconds after a 30-minute rest and remix. The FDOT hot fluidity test runs grout at 90°F through 400 ft of 1 in. tube for an hour, and efflux must still be under 30 seconds.
- Bleed is checked by the wick-induced bleed test, which must show 0.0 percent at 3 hours, and by the Schupack pressure bleed test (ASTM C1741) at 50 psi. The inclined tube test (EN 445) limits bleed to 0.3 percent.
- Chloride is limited to 0.08 percent by weight of cement. An accelerated corrosion test runs 1,000 hours at 0.2 V.
- Wet density is checked on site with an API mud balance.
- Bagged grout should be stored on site no more than a month, and material older than 6 months should be retested.

The pressure bleed test reflects a physical fact. Grout in a tall tendon is under head. Where the height difference exceeds about 6 ft, or vertical tendons exceed 20 ft, the manual calls for pressure bleed testing because the head squeezes water out of the grout through the strand interstices, and that water rises to the top. That is the mechanism behind many of the failures in this course.

How grout voids and bleed form

A void in a grouted tendon has a few possible origins, and an inspector who opens a tendon can often tell which by what is inside.

Incomplete filling. If grouting stops early, an outlet is closed before air is purged, a duct is blocked, or the pump loses pressure, the duct is never filled. FHWA-HRT-13-028 says that when a void is found, the inspector should look for grout residue on the duct wall, anchor plate and strand ends in the air space. No residue indicates the space was never filled. Residue suggests the grout was there and then subsided.

Bleed and subsidence. Plain cement grout is a suspension. As it sets, solids settle and water rises. In a tendon, the strand bundle acts like a wick: water travels along the interstices of the seven-wire strands and collects at high points and anchorages. When that water is later absorbed or evaporates, a void remains, and the strand that was standing in water is left at an air-water interface, which FHWA-HRT-13-028 identifies as a particularly severe location for corrosion.

Entrapped air. Inadequate venting, strands pressed against the duct wall, strand congestion and poor grout consistency trap air. FHWA-HRT-13-028 notes that air voids larger than about 0.1 in. that intersect the steel can locally start corrosion early.

Segregation. Prepackaged thixotropic grouts were adopted after 2001 to eliminate bleed. But forensic work on newer bridges found that these grouts could also segregate. The guideline lists four textures found in opened tendons:

- **Type 1:** segregated wet, plastic, soft grout with a clay-like consistency.
- **Type 2:** segregated grout with black striated layers, identified as unmixed or segregated silica fume.
- **Type 3:** segregated dry grout with a chalky white consistency.
- **Type 4:** hardened, gray, dry grout, the only acceptable condition.

Where several types occurred together, type 4 was at the bottom of the duct and types 1 and 2 at the top and at high points, showing gravity at work. The guideline states that corrosion-induced failures occurring soon after construction, even where chloride was within the 0.08 percent limit, strongly indicate that segregation, subsidence and incomplete filling are major issues.

Layers of corrosion protection

Chapter 5 of the FHWA manual frames tendon durability as a set of layers, each of which must be breached before the steel corrodes. It lists six levels, from the outside in:

1. **The surface.** Wearing surfaces, overlays, sealers and coatings, plus drainage and expansion joint details that keep water off the structure.
2. **Concrete cover and joints.** Structural concrete around internal ducts, epoxy in match-cast joints, and pour-backs over anchorages.
3. **The duct.** A continuous, sealed galvanized steel or polyethylene duct with sealed couplers.
4. **The grout.** Alkaline cementitious grout that fully encases the strand.
5. **Sheathing.** Additional encapsulation used in some systems.
6. **The strand or bar itself.** Coatings such as epoxy-coated strand.

The manual notes that existing bridges typically rely on levels 2 through 4. That is, most of the protection in the inventory comes from concrete and joints, the duct and the grout. The PTI/ASBI M50.3-12 guide specification, as the manual describes it, uses a parallel scheme of protection levels, PL1A, PL1B, PL2 and PL3; the manual points to Section 3 of M50.3-12 for minimum anchorage protection.

FHWA-HRT-13-028 makes the same point in two lines. The first line of defense is sealing the duct from external corrodants: water, air, chloride and carbon dioxide. The second is direct contact between strand and high-pH grout. If one line is lacking,

the other can still protect the steel. If both fail together, corrosion starts.

The practical consequence for the inspector is that a single defect rarely explains a failure. A void at a high point is a problem only if water, oxygen or chloride can reach it, or if bleed water is already inside. A leaking expansion joint is a problem for the tendons only if it drains onto an anchorage whose pour-back has separated and whose tendon has a void. When reviewing a bridge, look for places where several layers are weak at once.

Fallacies the failures exposed

The manual's corrosion chapter describes what investigators found when tendons began to fail. It reads as a list of assumptions that turned out to be wrong:

- **Cover is continuous.** It was breached at joints, at anchor block-outs and at pour-backs.
- **Epoxy joints seal.** Early segmental construction sometimes used no joint epoxy, or epoxy on one face only. The manual notes that Texas was the first to require epoxy on both faces. Imperfect joints let water reach internal ducts crossing the joint.
- **Grout fills the duct.** Voids were found from bleed and from entrapped air.
- **Admixtures help.** Expanding admixtures intended to offset shrinkage instead produced voids and, in some cases, split ducts.
- **Ducts are sealed.** Seams leaked in galvanized ducts, and polyethylene ducts split.
- **Workmanship defects get fixed.** Holes punched in ducts with a hammer and nail to release air were left open.
- **Pour-backs protect anchors.** Pour-backs cracked and separated, especially under leaking joints.

Section 5.5 of the manual adds detail on anchorages. Shrinkage and separation of concrete backfill in anchor block-outs in the top slabs of some segmental bridges created pathways to top internal tendons. Similar shrinkage cracks occurred in deck pockets left to access top tendons in I-girder construction. Separation of pour-backs at anchorages under expansion joints, combined with incomplete grouting, let run-off recharge grout voids and start corrosion.

The phrase "recharge grout voids" is worth noting. A void that was dry may stay harmless. A void that is wetted again and again, with oxygen available, is the worst case. FHWA-HRT-13-028 describes repetitive wetting and drying, perhaps from periodic water infiltration and aided by temperature swings, as a worst-case scenario for strand corrosion.

Named bridges. The manual's bibliography includes reports on the Mid-Bay Bridge post-tensioning evaluation (Corven, 2001) and corrosion evaluations of tendons on the Niles Channel Bridge (Powers, 1999; Sagues, 1999), both in Florida, and FDOT's "New Directions for Florida Post-Tensioned Bridges" (2002). FHWA-HRT-13-028 refers to a tendon failure in the Varina-Enon Bridge in Virginia, a Texas opened anchorage on the Carbon Plant Road bridge over IH-37, and an Italian bridge where a tendon failed less than 2 years after construction. This course does not quote findings from the primary reports on those bridges. It uses the two FHWA documents' descriptions only.

Lessons from forensic studies of newer grouts

A key lesson of FHWA-HRT-13-028 is that the post-2001 move to prepackaged thixotropic grouts did not end the problem. Most grouts before 2001 were mixtures of cement, water and admixtures, mixed at the site. PTI and some States revised their grout specifications in 2001 and 2002, leading to prepackaged, preapproved thixotropic products intended to eliminate bleed water. Yet corrosion failures continued on relatively new bridges, and limited forensic studies found segregation, soft grout,

bleed water, and high chloride and sulfate. The guideline is careful to add that not all prepackaged grouts showed these problems.

The failed tendon at 8 years. The guideline shows a cross section of a tendon that failed 8 years after construction. Chloride in that grout was below the 0.08 percent limit. Hardened gray type 4 grout filled the lower part of the duct. Chalky white type 3 grout appeared as a pocket and as a thin layer, about 0.04 in. thick, on top of the gray grout. Strands were pressed against the duct wall at the upper right, and corrosion products were on the upper strands.

Opened anchorages. In other opened anchorages there was no chloride contamination and the duct was completely filled, yet the grout was mainly chalky type 3 with a network of cracks, or soft type 1 in the center, and strand ends showed corrosion. Full filling was not enough; quality mattered.

Carbon Plant Road. In the Texas anchorage, soft type 1 grout was in the upper region and gray type 4 below. Free water flowed out when the anchorage was opened, and strands in the soft grout and air space were corroded. TxDOT's analysis found chloride, sulfide, sodium and potassium in the type 1 grout. FDOT, on other samples, found higher chloride and calcium in type 1 grout than in the other types.

Sulfate. The guideline discusses sulfate as a second chemical concern. It cites a European upper limit of 4.5 percent by weight of cement for sulfates and 0.01 percent for sulfides, and explains that hydrolysable ions, sulfate included, can acidify the solution in crevices such as the contact lines between wires, increasing the corrosion rate.

The contaminated grout. The guideline also responds to disclosure that a grout product with chloride above 0.08 percent may have been used on roughly 100 PT bridge projects, with values as high as 5.27 percent by weight of grout reported on one bridge. It notes that contamination may have varied by production lot. That is why its sampling plans pay attention to grout lots and batches: a lot is typically 40,000 to 250,000 lb, made of batches of about 1,100 lb.

Chloride threshold. The guideline explains that the 0.08 percent limit is not the corrosion threshold. For good-quality, high-alkalinity grout, the threshold is understood to be higher, but it is a distribution, not a single number. For conventional reinforcement it cites ACI's 0.2 percent and research values from about 0.39 to 1.16 percent by weight of cement. But it also says that where steel is exposed in air with free water present, the threshold is effectively zero. Chemistry and physical condition have to be judged together.

Construction quality: the first inspection

Most of what can go wrong inside a tendon is decided during construction, and the FHWA manual treats grouting as a controlled operation with its own inspection. Knowing that sequence helps an in-service inspector judge what records to ask for.

Before grouting. Tendons should be grouted soon after stressing, with temporary protection if grouting is delayed. Ducts are proved with a torpedo to confirm they are open, and the system is air-pressure tested as described in PTI/ASBI M50.3-12 Section 13.1 to find leaks. Grout material must have passed lab trials, and its storage time is controlled.

Mock-ups. Where tendon geometry is demanding, such as height differences above about 6 ft or vertical tendons over 20 ft, the manual calls for pressure bleed testing and mock-ups so the grout and procedure are shown to work before production.

During grouting. Grout is pumped from the low point, outlets are closed in sequence once uniform grout flows from them, and fluidity and density are checked. Water is never added to restore flow.

After grouting. Section 4.3.8.3 of the manual sets a post-grouting inspection. For projects with fewer than 20 tendons, all inlets and outlets at anchorages and high points are drilled and inspected with an endoscope. For larger projects with tendons no longer than 150 ft, inspection continues until 20 consecutive tendons are void-free, then drops to every other tendon. If a void is found, the last 5 and the next 20 tendons are inspected. Voids are filled by volumetric vacuum grouting within 72 hours, and caps within 4 hours. A grouting report is due within 72 hours. Inlet caps are recessed at least 1 in. and filled with epoxy.

Why this matters later. FHWA-HRT-13-028 treats construction and inspection records as one of the four factors in the probability that a tendon has a defect. A bridge with complete grouting logs, lot numbers, void inspection results and repair records lets an owner sample less and interpret more. A bridge with no records is scored at the top of that scale.

Inspecting existing tendons: the four-step process

FHWA-HRT-13-028 is written for owners who need to know whether in-place grout in an existing bridge is deficient. Its Chapter 2 sets out the goals: decide which tendon types to sample, how many, how to get samples without harming durability, which tests to run, how to record results, how to restore the openings, and how to decide on future inspection.

The guideline recognizes a tension. Intrusive sampling is the only reliable way to see grout and strand, but every hole drilled or cap removed is a new path for corrodants if it is not properly restored. The sampling plan therefore tries to collect enough to be statistically meaningful while opening as few tendons as possible.

Two options. Option 1 checks chloride only, for owners concerned with contaminated grout. It assumes no physical deficiencies; if any are found, the owner should move to Option 2. Option 2 checks all deficiencies, chemical and physical. Each option has two levels. Level 1 is a preliminary screening; level 2 is a more comprehensive, higher-confidence inspection. Option 2 uses 75 percent confidence for level 1 and 95 percent for level 2.

Option 1 with records. At level 1, take at least three random samples per grout lot from the primary tendon types, or one sample from 50 percent of all batches, whichever is larger. If any sample exceeds 0.08 percent chloride by weight of cement, go to level 2, which takes at least one random sample per batch. If records are incomplete or missing, follow the Option 2 statistical approach.

Option 2 steps.

1. Review the as-built plans, PT shop drawings, specifications and construction records.
2. Walk the full length of the bridge for a visual inspection. No special equipment is needed. The aim is to judge the overall condition and spot signs of distress.
3. Obtain grout samples, document the grout condition and look for tendon defects. This may need special tools.
4. Test, analyze, grade and decide on action.

What the walk-through looks for follows directly from the visual evaluation table in the guideline: signs of grout leakage, workmanship, cracked concrete, external duct condition, voids in external tendons, signs of water leakage, and the state of corrosion protection. Each is scored from 5 for a major defect to 1 for none, and the highest score governs that factor. In practice that means looking for grout stains at joints and ducts, rust staining, efflorescence at pour-backs and blisters, cracks along duct paths, split or patched polyethylene ducts, tape-wrapped joints, wet box interiors, blocked drains and leaking expansion joints over anchorages.

Risk-based selection of tendons

FHWA-HRT-13-028 ranks tendons by risk, the product of a probability of defect indicator P and a consequence of failure indicator C, each on a 1-to-5 scale. Tendons are placed in low, medium or high risk using a risk matrix.

Probability of defect, P. A weighted sum of four factors:

Factor	Weight	Scale examples
Overall bridge condition	0.15	Poor 5 ... Excellent 1
Construction and inspection records	0.15	None 5 ... very comprehensive 1
Visual evaluation	0.30	Major defect 5 ... none 1
Tendon geometry and length	0.40	Long multispan with large curvature or tall vertical 5 ... short straight 1

Geometry carries the largest weight because experience showed defective grout is unlikely in short straight tendons and more likely in long multispan tendons with large curvature changes and large height differences, particularly tall vertical tendons. That is consistent with the bleed mechanism: head and length drive water to the high points.

Consequence of failure, C. A weighted sum of three factors: cost of repair or replacement (0.4), element or tendon redundancy (0.4), and bridge importance (0.2). The redundancy scale runs from 5, where losing some tendons would cause catastrophic failure, down to 1, where the tendon does not contribute to resistance. The guideline gives examples: cantilever tendons in balanced cantilever bridges are more redundant than bottom continuity tendons, because part of the cantilever tendons were needed only during erection and were left in place. Diaphragm tendons are highly redundant because of the ordinary reinforcement around them. Bridge importance is 5 for critical bridges, 3 for non-critical and 1 for less important bridges.

Illustrative calculation. Consider a hypothetical group of long draped continuity tendons on a bridge in moderate condition (4), with limited records (4), moderate visual defects such as efflorescence at blisters (4), and geometry scored 5. $P = 0.15(4) + 0.15(4) + 0.30(4) + 0.40(5) = 0.6 + 0.6 + 1.2 + 2.0 = 4.4$. If repair cost is high (4), redundancy is 4, and the bridge is critical (5), $C = 0.4(4) + 0.4(4) + 0.2(5) = 1.6 + 1.6 + 1.0 = 4.2$. These numbers are illustrative only; the risk category comes from the guideline's matrix (Figure 37), and a group scoring this high on both axes would be expected to fall in the high-risk band.

Acceptable undetected fraction. Table 10 of the guideline sets the fraction of tendons with deficient grout that the owner accepts might go undetected. It depends on element risk and on how much structural impact sampling would cause. For high-risk elements it ranges from 20 percent, where sampling impact is high, to 10 percent where it is medium or low. For low-risk elements it is 30, 30 and 20 percent.

Minimum number of tendons. Tendons with similar likelihood of defect are grouped, and each group is treated as a population. Because sampling is without replacement, the guideline uses the hypergeometric distribution and tabulates the minimum number of tendons needed to detect at least one deficient tendon at 75 percent (Table 11) and 95 percent (Table 12) confidence.

Illustrative check. For a hypothetical group of 40 tendons in which 10 percent (4 tendons) are deficient, the probability that a random sample of n contains none is $C(36,n)/C(40,n)$. Working this out, 12 tendons give about a 78 percent chance of finding at least one deficient tendon, and 21 tendons are needed to reach 95 percent. If 20 percent (8) were deficient, 12 tendons would give about 96 percent. These figures are computed here for illustration; use the guideline's Tables 11 and 12 for an actual plan.

Where to look: strategic sampling locations

Once the number of tendons is set, FHWA-HRT-13-028 Chapter 7 says the target tendons should be chosen randomly, and the sampling points on each should be placed where deficient grout is most likely, at anchorages, high points and couplers. At least one grout sample per selected tendon is taken under both options.

Grout caps first. If the tendon has a permanent grout cap, the simplest sampling point is inside the cap, and the guideline names this the first option. A cap can be removed entirely or partly cored, with a 3 to 4 in. core taken toward its upper part; the core is saved to restore the cap.

Locate internal tendons by GPR. Before opening any internal tendon, find it with ground penetrating radar. The guideline specifically says not to rely on as-built plans, because tendon locations may have changed during construction.

Balanced cantilever, continuity tendons. These are internal tendons in the bottom slab, usually anchored in blisters. Remove or core the grout cap, sample the grout and inspect the strands at the anchor head and any void. If there is no cap, or the cap shows a void, drill through a grout port into the trumpet, with extreme care not to hit strand, and inspect any void with a videoscope. Inspect both ends of each selected continuity tendon. If severe corrosion is found, remove the whole cap and the grout over the anchor head. Where anchors were protected by a concrete pour-back and no cap, chip concrete over the duct at the end of the blister to reach the grout.

Balanced cantilever, cantilever tendons. These are reached from the deck, so the guideline recommends night work for traffic control. Chip out the PT block-out over at least a 1 ft by 2 ft area, core the cap face if present, and inspect at least two points per tendon.

Span-by-span segmental, external tendons. At least three points per tendon: the grout cap at the diaphragm, the top duct coupler next to the diaphragm, and the lower duct coupler near a deviator.

Cast-in-place box girders. Draped internal web tendons are often unreachable at end diaphragms but can be probed from inside the box near the anchorages. For a two-span continuous bridge, inspect at least three points: next to the anchorage, at a high point and at the lowest point, with more for longer units.

Spliced girders. Typically three or four end-to-end internal tendons per multispan unit, and the anchorages are hard to reach at the bridge ends. For a three-span unit, at least three points: next to the anchorage, at the cast-in-place closure joint near the pier, and at the high point over the pier.

How to open a tendon and what to record

Chapter 6 of FHWA-HRT-13-028 describes the field method.

External tendons. Document the general appearance and inspect the duct for cracks or connections that could admit corrodants. Access the grout by removing the end cap or by cutting a window in the duct. Get the duct wall thickness from the construction documents and cut with a plastic cutting wheel or a depth guard that limits grinding to the wall thickness. Strands may be pressed against the inside of the duct at some point around its circumference, so cut with care. A dial depth gauge can measure the depth of a void at the top of the duct.

Internal tendons. Document the end caps, open the planned number, and sample by light chipping, with a plastic sheet under the anchorage so the sample is not contaminated. If grout from the caps is good and chloride is acceptable, intermediate sampling should not be needed. If the grout looks problematic, is contaminated or otherwise defective, inspect more caps,

intermediate points or both. To check for air pockets at intermediate high points with minimal disruption, drill with a 1 in. bit; the guideline notes that drill noise and vibration change noticeably when the tendon is reached, which helps avoid hitting strand. Inspect any pocket found with a borescope. Where samples are needed at intermediate points, a small excavation of about 6 in. diameter can expose the strand and grout. Excavations must not cut or damage reinforcement or the tendon.

Before opening. Place an open bag or sealable container under the opening to catch any free water that runs out, because that water is evidence.

What to look for.

- Any air pocket or void along the top of the duct, and whether grout residue is present on surfaces in the void.
- Free water.
- Presence and extent of corrosion on strand and anchorage.
- Differences in grout color, consistency or segregation.
- Voids within the grout, recorded for each grout type.

What to collect. Using a clean tool and clean plastic or rubber gloves, put into clean freezer bags any water, accessible corrosion products, a sample of each grout type, and anything else of interest. Collect promptly, because air exposure can change the grout, corrosion products and water. Where strands press against the duct, take grout from the diametrically opposite side.

Laboratory analysis. Composition is found by wet chemistry and by methods such as ion chromatography, X-ray fluorescence and energy dispersive spectroscopy. Structure is found by petrography, electron microscopy and X-ray diffraction. As an alternative to exposing strand, potential measurements can be made to assess its corrosion state.

Recording. The guideline provides a bridge representation for identifying sampling locations and charts for recording each sample's location, observations and analysis. Consistent records are what make reinspection meaningful.

Grading tendons and choosing actions

Chapter 9 of FHWA-HRT-13-028, as amended on January 7, 2014, grades each tendon from 1 to 10, higher being worse, using chemical deficiency (CD) classes based on chloride by weight of cement and physical deficiency (PD) classes.

Class	Definition
CD1	$Cl \leq 0.08$
CD2	$0.08 < Cl \leq 0.20$
CD3	$0.20 < Cl \leq 0.50$
CD4	$Cl > 0.50$
PD0	Sound grout
PD1	Grout air pocket
PD2	Exposed strand or tendon
PD3	Soft or segregated grout
PD4	Surface corrosion, no section loss
PD5	Corrosion with less than 5 percent section loss

PD6	Partial or full fracture, 5 percent or more section loss
-----	--

The actions are A1 none, A2 expand sampling, A3 reinspect in 5 years, A4 reinspect in 2 years, A5 tendon monitoring, A6 consider repairing the deficiency (for PD1 to PD3), A7 structural evaluation and load rating, and A8 tendon replacement.

Option 1 (Table 32). For sound grout and chloride only: CD1 is grade 1 with no action; CD2 is grade 5, reinspect in 5 years; CD3 is grade 7, expand sampling and reinspect in 2 years, with monitoring; CD4 is grade 9, with the same actions. If strand corrosion or fracture is found, the tendon is graded under Option 2.

Option 2 (Table 33). The highest PD governs. The guideline's examples: CD1 with an air pocket (PD1) is grade 2 with no action, although if the pocket is long and larger than 0.5 in., regrouting (A6) may be considered. If strands also show surface corrosion without section loss (PD4), the grade becomes 6 with actions A3 and A6. PD6 is grade 10, calling for expanded sampling, 2-year reinspection, monitoring, repair, structural evaluation and replacement.

Section loss arithmetic. Section loss counts fractured strands as a share of the tendon. One fractured strand in a 22-strand tendon is $1/22 = 4.5$ percent, PD5. One in an 18-strand tendon is $1/18 = 5.6$ percent, PD6. The same single break moves the tendon from one class to the worst.

Worked example from the guideline. A span-by-span bridge with complete grouting records had an Option 1 level 2 inspection of 10 tendons. Sixty percent had chloride between 0.08 and 0.20 percent (CD2, grade 5) and 40 percent were below 0.08 (CD1, grade 1). The conclusion was to stop sampling and reinspect the group 1 tendon types in 5 years.

A second example with no records used Option 2 level 2. All chloride was below 0.08, but 30 percent of tendons had soft or segregated grout, voids, exposed strands and more than 5 percent section loss, graded 10. The course of action combined expanded inspection, replacing tendons with more than 5 percent loss, regrouting voids, load rating with the PT section loss, and reinspection in 2 years, extended to 5 if satisfactory. Monitoring might not be needed because chloride was low.

The guideline stresses that these tables are guidance and that sound engineering judgment must be applied.

Restoring openings, NDT and monitoring

Restoration. Every opening made for inspection is a new breach in the protection layers, so Chapter 8 of FHWA-HRT-13-028 gives temporary and permanent procedures.

- **External tendon, temporary:** vacuum or blow out dust and soft material, cover exposed strand with an approved hydraulic cement grout mortar, refit the two half pieces of polyethylene duct, seal the cut lines and wrap at least 4 in. beyond each end with high-performance waterproof tape.
- **External tendon, permanent:** the same, but with heat-shrink sleeve extending at least 4 in. beyond each end.
- **Internal tendon, temporary:** clean, cover strand with hydraulic cement mortar, bend a metal duct back over the mortar, and fill to the concrete surface with hydraulic cement mortar or magnesium ammonium phosphate concrete.
- **Internal tendon, permanent:** clean, remove part of the duct, cover the strand with grout mortar and restore the duct and concrete per the guideline's details.
- **Grout caps:** restore cored or partly cut caps and apply an elastomeric coating.

Voids found and judged worth filling are regouted. The construction manual's method for voids found after grouting is volumetric vacuum grouting, which measures the void volume and fills it under vacuum.

Anchorage protection in rehabilitation. The construction manual's anchorage checklist is also a good rehabilitation checklist: fully filled tendon, anchor and cap; a permanent cap; a pour-back of high-bond, low-shrink, sand-filled epoxy grout with at least 1-1/2 in. cover over the cap and plate edges, cast on a cleaned, roughened substrate; seal coats on pour-backs; inside boxes at interior piers, a seal coat lapping at least 12 in. onto the concrete around the anchor plate; drip grooves around upper blisters; drip flanges and protection from leaking expansion joints; in coastal areas, skirts or baffles at expansion joints against wind-borne spray; and box girders that are ventilated, watertight and drained.

NDT. For reinspection, FHWA-HRT-13-028 lists NDT methods that may be considered: main magnetic flux, magnetic flux leakage, pulsed eddy current, magnetostrictive sensors, microwave thermorefectometry, remnant magnetism, vibration, ultrasonic pulse velocity and acoustic emission. It then states the key limitation plainly: section loss or fracture of wires or strands within internal tendons, and within deviation blocks and anchorages of external tendons, where problems are most likely, cannot currently be detected by these methods. The guideline treats improving them as ongoing research. Check the current state of the art before relying on any of them.

Monitoring. The guideline names monitoring for wire and strand breaks as a way to ensure fractures are found in time, with passive acoustic emission and remote monitoring commercially available.

Putting it together. For an inspector, the lessons from the failures come down to a short list:

1. Get the shop drawings and grouting records before going on site.
2. Walk the bridge looking for water: leaking joints, wet boxes, blocked drains, stains, efflorescence and separated pour-backs over anchorages.
3. Concentrate intrusive inspection on anchorages, high points, couplers and long draped or vertical tendons.
4. Open tendons carefully, catch the water, photograph and bag every grout type, and record the residue.
5. Grade by both chemistry and physical condition, because low chloride does not mean safe grout.
6. Restore every opening to a standard at least as good as the original.
7. Do not treat a clean NDT result as proof of sound strand inside an internal tendon or anchorage.

Key takeaways

- Bonded PT relies on layered protection: surface, concrete cover and joints, duct, grout, sheathing and the steel itself. Failures occur where several layers are breached together.
- Voids form from incomplete filling, bleed and subsidence, entrapped air and segregation; residue in a void indicates subsidence, while no residue indicates the duct was never filled.
- Only hardened gray (type 4) grout is acceptable. Soft, striated and chalky grouts found at high points and anchorages are associated with strand corrosion even below the 0.08 percent chloride limit.
- Inspection of existing tendons is risk-based: review records, walk the bridge, then sample selected tendons at strategic high points and anchorages, locating internal tendons by GPR rather than as-built plans.
- Grade tendons by chloride and physical deficiency per FHWA-HRT-13-028 Tables 32 and 33, and restore every opening; common NDT methods cannot yet reliably detect strand loss inside internal tendons, deviators and anchorages.

References

1. FHWA, Post-Tensioning Tendon Installation and Grouting Manual, FHWA-NHI-13-026, 2013
2. AASHTO, LRFD Bridge Design Specifications, 9th Edition, 2020

3. Theryo, T.S., Hartt, W.H., Paczkowski, P., Guidelines for Sampling, Assessing, and Restoring Defective Grout in Prestressed Concrete Bridge Post-Tensioning Ducts, FHWA-HRT-13-028, Federal Highway Administration, October 2013 (amended January 7, 2014).
4. PTI/ASBI M50.3-12, Guide Specification for Grouted Post-Tensioning, and PTI M55.1-12, Specification for Grouting of Post-Tensioned Structures (as cited in FHWA-NHI-13-026).

Study text only; the final quiz is taken online. Verify all references against the edition your agency has adopted.