Technical NOTES

From PTI/ASBI M-50: Multistrand and Bar Post-Tensioning Committee Issue 25 • October 2026

UN-DUCTED EXTERNAL POST-TENSIONING WITH EPOXY-COATED STRAND

INTRODUCTION

Un-bonded, un-ducted, and replaceable – external post-tensioning (PT) tendons are gaining interest within the concrete bridge community. The ability to address unforeseen issues that may arise within a post-tensioning system has always been valued by bridge engineers. Un-bonded external PT tendons provide bridge designers and owners the flexibility to address some of these issues through the ability to inspect and replace tendons while the bridge is in-service. There are numerous benefits with external, unbonded post-tensioning. Internationally, countries including France, Germany, and Japan, have been using replaceable post-tensioning tendons for decades. Several benefits of external post-tensioning tendons highlighted in the FHWA report, "Assuring Bridge Safety and Serviceability in Europe" (FHWA-PL-10-014) are as follows.

- Quality of fabrication is enhanced.
- Inspecting and maintaining the tendons is enhanced.
- Replacement of the tendons is facilitated.
- Re-tensioning the tendons is possible if provided for in the design.
- Web thickness can be reduced without tendons in the webs, reducing dead load.

This publication will focus on un-ducted external PT tendons consisting of multiple epoxy-coated strands (ECS). Use of ECS can improve the durability of external post-tensioning tendons with a robust factory applied epoxy-coated protection layer. In addition, the tendons are accessible and can be inspected and replaced if necessary. This technology has been in use for nearly 30 years in Japan with no in-service issues.

BACKGROUND

ECS is a proven technology for prestressed concrete structures that improves bridge durability and resiliency. ECS is coated with an epoxy resin. This epoxy covers both the outer surfaces of the strand as well as filling all internal voids around each wire, thereby providing superior corrosion protection and resistance against fretting fatigue. ECS have been used in numerous structures worldwide. ECS have become the post-tensioning system of choice for external tendons in Japan. As engineers and owners demand alternatives to traditionally grouted systems, ECS have increasingly become recognized as a proven and viable option providing improved tendon inspectability and replaceability in the case of un-ducted systems. By employing a few design and job-site modifications, ECS can be readily used for external tendon applications. Figure 1 shows the interior of a concrete box girder utilizing un-ducted external post-tensioning with ECS.

Figure 1 — Concrete box girder with un-ducted external post-tensioning using ECS - Laurel Fork Bridge (Source: Sumiden Wire / VSL)

There are notable differences in the epoxies used to coat strands and reinforcing bars. The primary distinction lies in the surface preparation method. For epoxy-coated rebar, the process involves just two main steps: first, the removal of mill scale from the hot rolling process through mechanical shotblasting; second, heating the descaled rebar before applying the epoxy powder coating. In contrast, the surface

preparation for ECS begins during the production of individual wires, where mill scale is removed from the wire rod. The wire rod is then drawn into wire and subsequently stranded into PC strand, which is heated to over 700°F (370°C) in a low-relaxation process and cooled in a water bath. After this, the finished strand undergoes chemical cleaning and is heated again prior to the epoxy powder coating application. These additional surface preparation steps, result in superior surface adhesion between the epoxy resin and the steel in ECS compared to epoxy-coated rebar. Research has shown that an additional benefit of ECS is the adhesion of the epoxy to the individual wires. This adhesion isolates the wires and limits any potential corrosion to the exposed surface(s). In addition, ECS has a substantially thicker epoxy coating when compared to epoxy-coated rebar.

This publication is intended to provide information to users on the un-ducted external post-tensioning with ECS to assist in the deployment of this technology. Included in this publication are descriptions of this technology's unique design considerations, system qualifications, components, and installation processes.

DESIGN CONSIDERATIONS

Use of ECS can produce different theoretical tendon forces and elongations compared to bare strand due to two primary factors:

1. Coefficient of Friction: Experience in Japan has shown that the coefficient of friction for ECS can be slightly higher than for bare strand. A range of angular friction coefficient (μ) of 0.17-0.21/rad is recommended.
2. Anchor Set: Larger anchor set should be expected as the wedges need to travel a longer distance to properly grip the strand. Contact the supplier for estimates on seating loss specific to the equipment being utilized. Seating loss values can range between ½" to 7/8" depending on whether power seating or friction seating equipment is used.

Bridge designers should consider these factors, and bridge constructors should verify them with their post-tensioning supplier. Design considerations also include noting the differences in the behavior of bonded and unbonded tendons relative to the structure.

Tendon Vibration: Un-grouted and un-ducted ECS external tendons can be expected to exhibit noticeably higher vibrations when impacted, such as during construction activities. This increase in vibration occurs due to the lack of dampening effects resulting from the absence of grout or other fillers within ducts. However, this heightened potential for vibration has not led to any reported in-service fatigue issues in the hundreds of un-grouted, un-ducted ECS external tendon structures constructed globally since 1994. These structures encompass a wide range of tendon lengths and have not included any vibration dampening measures. Vibrations caused by traffic or other in-service factors have not been observed to induce significant vibrations to external tendons. Consequently, no additional damping measures were necessary above that which would have been required for grouted external tendons.

To evaluate the potential for un-ducted strand tendon vibration issues, a dynamic analysis should be performed on the completed structure to determine the frequency of the first fundamental vertical mode of vibration within each span. The controlling tendon vibration for each span will then be determined by determining vibration frequency for a single strand at its effective stress. The tendon free length will be based on the individual tendon lengths created between tendon anchorages and deviation points. The vibration frequency of the tendon can be calculated using the vibrating wire equation for the span free lengths and from this the controlling tendon frequency can be determined.

$$f_n = \frac{n}{2L}\sqrt{\frac{T}{m}}$$

Where:

f_n = natural frequency for the nth harmonic
n = harmonic number, 1 for the first harmonic
L = Unsupported length of the tendon (ft)
T = Tension in the tendon (lb)
m = Tendon mass per unit length (slugs/ft)

It is recommended that the controlling tendon frequency be greater than the span vertical frequency to avoid resonance of the tendon due to future service loadings on the structure. Based on experience, tendon free lengths of approximately 82 ft (25 m) are acceptable. (Ref. "*SETRA Design Guide for Prestressed Concrete Bridges Built Using the Balanced Cantilever Method*", Section 3.1.3.4, 2003 version).

Tendon replaceability: Provisions for the replaceability of the strands must be made during the design. FHWA publication, *Replaceable Grouted External Post-Tensioned Tendons* (Publication No. FHWA-HIF-19-067 October

2019), while intended for grouted post-tensioning, includes design and detailing recommendations that can be applied to un-ducted post-tensioning. Although this system is replaceable, most (if not all) replacements would require removal of the existing tendon in its entirety. Removal and replacement of individual strands within a tendon is not practical in most situations. The individual strands cannot be extracted and new replacement strands installed due to friction and compacting effects at deviators and/or inside a multi-strand tendon unless all strands are completely isolated within a tendon. To replace a tendon, the typical method of replacement would be to first detension the original tendon. This detensioning process typically involves a carefully planned cutting of the individual strands, typically near one of the anchorages, to best account for the expected recoil of each strand as it ruptures. Because detensioning is not expected to be a common occurrence, the additional space and cost needed to encapsulate sufficiently long strand tails at each anchorage location to facilitate a more controlled detensioning is not considered to be financially justified.

SYSTEM QUALIFICATIONS

The PT system needs to meet wedge plate, anchorage tensile (efficiency) and load transfer tests as outlined in PTI M50.3-19(24) Section 4.4.1. Since un-ducted external post-tensioning using ECS results in a tendon that is unbonded from the structure, which raises fatigue concern, the system must satisfy European Assessment Document, "Post-Tensioning Kits for Prestressing of Structures", EAD160004-00-0301 Article 2.2.2 Resistance to Fatigue. Additionally, diabolos (see component descriptions below) are required at deviator locations, which requires testing conducted per EAD 160004-00-0301 Article C.5.1 and Article C.5.2 and satisfying the acceptance criteria of Section 2.2.6(a) and Section 2.2.6(b) for radii less than established minimum values. System leak tightness tests must be completed for the sealed and ducted sections per the requirements shown in Specification 3.1.4 in this Technical Note.

COMPONENT DESCRIPTIONS

Epoxy-coated pre-stressing strand: Manufactured to ASTM A416/A416M and coated with an epoxy layer per ASTM A882/A882M for enhanced corrosion resistance. The use of ECS requires bite-through wedges designed for this strand type. Bite-through wedges differ from standard wedges; notably the teeth are larger to ensure they fully penetrate the epoxy coating and grip onto the steel wires. Figure 2 shows the cross-section of an ECS. In special cases, the thickness of the epoxy coating can be increased when excessive abrasion and wear are anticipated during tendon installation. If the coating thickness is increased, it must remain within the tolerances of ASTM A882 as well as the maximum thickness compatible with the bite-through wedge to be used.

Figure 2 — Cross-section of Epoxy-Coated Pre-stressing Strand (Source: Sumiden Wire)

Diabolo deviator: A formed void in a deviator or diaphragm with trumpet-shaped ends to align and direct an external post-tensioned tendon through the concrete section. Figure 3 shows a schematic of a section taken through the center of the diabolo.

Deviator protective HDPE pipe: A length of HDPE pipe surrounding the tendon to provide abrasion protection to the ECS during both tendon installation and during the bridge's service life.

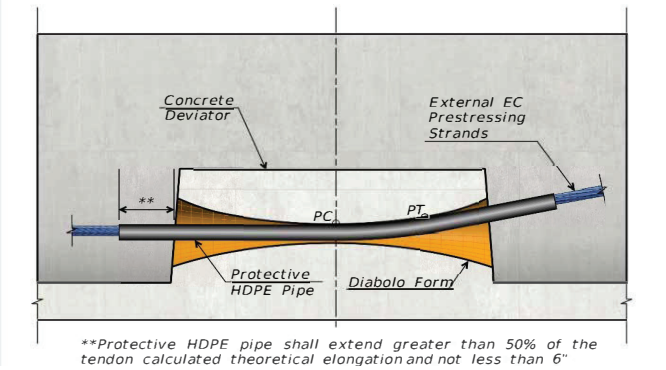


Figure 3 — Section taken at Deviator through Diabolo (Source: WSP)

Anchorage sealing device: A component located within a post-tensioning anchorage to retain the injected corrosion inhibiting material within the anchorage body. The corrosion inhibiting material is to protect the exposed metal components within the anchorage. This material

could be gel, grout, flexible filler, or another material that inhibits corrosion. Figure 4 shows an example of one possible sealing device. In this design, the retaining plate is pulled toward the wedge plate using the compression bolts after the tensioning operations have been completed and before the corrosion inhibiting material is injected into the grout cap. The compressible gasket material is compressed by the movement of the retaining plate forming a seal around each strand. Anchorage shall demonstrate through testing the encapsulation of the strand wedge interface within the anchorage body.

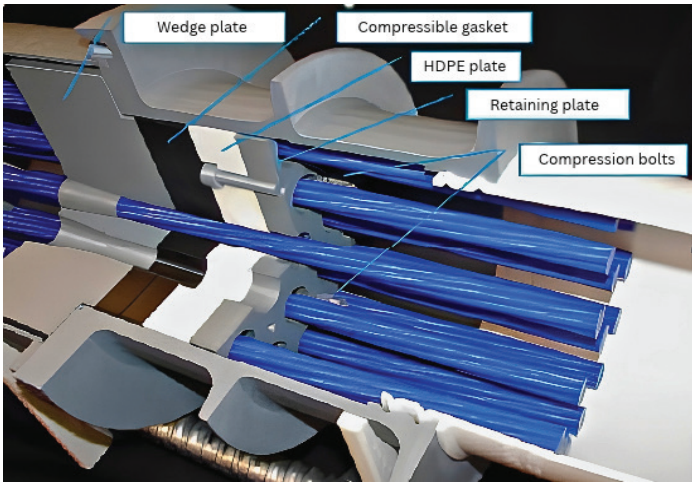


Figure 4 — Example Anchorage Sealing Device (Source: Dywidag)

STRAND INSTALLATION

It is recommended to install ECS by the pull method by first pre-assembling multi-strand tendons prior to installation. Pre-assembly helps ensure that the individual strands maintain parallel alignment along the entire tendon length, protects the interior strands from damage during tendon installation, and prevents damage to the individual strands' coating, which is more likely if the strands are installed using a strand-by-strand method using the pushing or pull method. Maintaining parallel alignment is critical for an ECS system because ECS have a slightly higher friction coefficient compared to traditional bare strands. This higher friction coefficient not only affects elongation performance but can also cause damage to the coating or, in the worst case, strand breakage if a misaligned strand is unable to self-align during stressing due to increased friction. This strand installation guidance section will focus on the pull method of strand installation because it is the most effective method for both protecting the coating from damage and maintaining parallel alignment among the individual strands.

The pull installation method requires that all the strands in the tendon be cut to length and bundled prior to installation. Figure 5a shows the placement of strands on a support frame, typically outside the structure, in preparation for cutting to length, and Figure 5b shows the operation of bundling the strands in the tendon. Strand-on-strand rubbing should be avoided to prevent coating damage during uncoiling. Figure 6 shows one example of a component—a strand compactor—used to form the bundle in a hexagonal shape as the strands are pulled into the structure. Other bundle shapes, such as a circular shape, can also be used, if the individual strands are kept parallel but hexagonal shape is preferred for compact (close-packed) ECS configurations to avoid or reduce relative movement between the individual ECSs. The strand compactor is typically made of rigid plastic or some other material that will not damage the strand coating and is manufactured in two half-components (such as three sides of a hexagon) to fit the number of strands being installed (as shown in Figure 5b and Figure 6). The two half-components are clamped together to compact the strand into the desired shape. The strand compactors are generally only used during installation and are not installed on the tendon during stressing operations. To retain the tendon shape after it has passed through a compactor, reinforced tape is typically placed at regular intervals (approximately every 10 feet) so that only one compactor is needed while installing a tendon.

(a) Placement of Strands on Frames

(b) Bundling Strands

Figure 5 — (Source: Sumiden Wire)

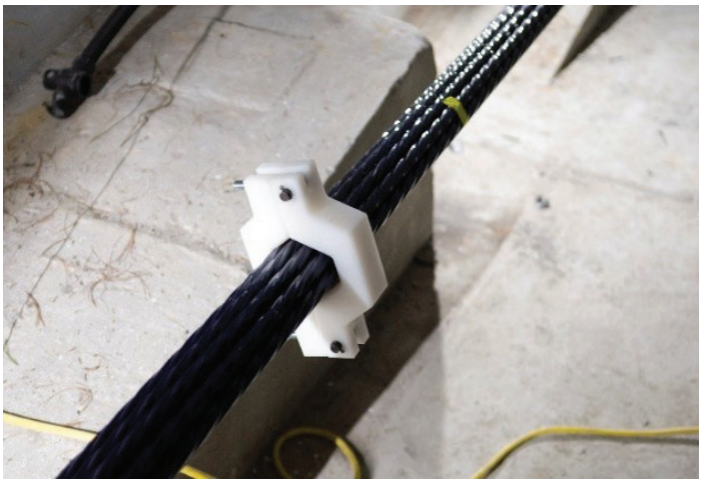


Figure 6 — Strand Compactor (Source: ASBI)

When using the pull installation method, the installer will need to select a method to grip the beginning of the tendon to pull it through the structure. Several different methods have been used. The following list are some examples of pull methods.

- Wire Mesh Cable Grips – Wire mesh cable grips (Figure 7) are commercially available products commonly used in the electrical wiring industry. When these grips are used to install an external tendon, a rubber tape is typically wrapped around and through the strand matrix to provide increased friction for the wire mesh cable grip to securely pull the tendon.
- Center Wire Hooks – The center wires for each strand in the tendon are exposed by carefully trimming away the outer wires. The exposed center wires are mechanically bent to form loops and bundled together to be used as pulling hooks (Figure 8).
- Welded Coupler – A special coupling device is welded to the end of each strand. The coupling device has a pulling attachment.

Figure 7 — Wire Mesh Cable Grips (Source: Sumiden Wire)

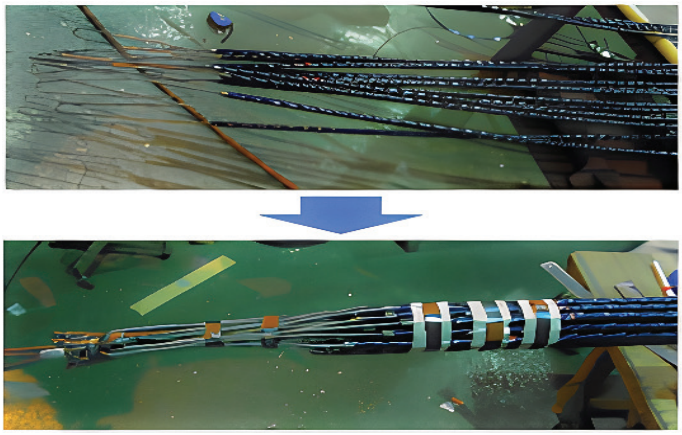


Figure 8 — Center Wire Hooks (Source: Sumiden Wire)

ECS tendons can also be installed using the strand-by-strand push or pull method; however, additional precautionary measures need to be taken. When strand-by-strand installation is performed, coating damage may occur due to strand-on-strand rubbing as the strand being installed slides past previously installed strand(s) which is more challenging inside bulkheads or deviators. Additionally, the risk of strand misalignment (i.e., becoming non-parallel) increases; therefore, more strand compactors (or other aligning devices) need to be used along the tendon length during installation to ensure proper parallel alignment. Maintaining parallel alignment becomes increasingly challenging using this method as the tendon length increases.

Maintaining strand orientation within the tendon strand bundle is important to limit strands from intertwining and to reduce friction between individual strands. Markings are routinely made on the individual strands located in the outer ring of the strand bundle and on the end surfaces of all strands to monitor strand positioning along the length of the tendon.

In Figures 5a and 5b, the ECS tendon is being preassembled outdoors in direct sunlight (UV exposure). It has been confirmed that ECS after 30 days of outdoor exposure meets coating adhesion requirements specified in ASTM A882. However, it is commonly known that long-term UV exposure deteriorates epoxy coating and the long-term anti-corrosion properties of epoxy coating during its use. The duration of UV exposure of ECS should therefore be minimized and stay within the 30-day exposure guideline. As previously stated, installation of ECS requires additional care to prevent damage to the epoxy coating. This additional care involves protecting the epoxy strand from abrasive surfaces during strand installation. Abrasion protective

components are needed at tendon anchorages, deviators, and at tendon temporary supports.

A rigid plastic ring that is sized for the post-tensioning anchorage opening can be placed at the anchor opening face to protect the strand from rubbing against the body of the anchor hole during installation. This protective ring is shown below in Figure 9a.

Temporary supports are also needed to support the tendon during installation. These supports should have protective coverings robust enough to protect the tendon from abrasive contact with the support during the tendon's installation. These coverings are typically cylindrical in shape (a typical example would be a PVC or PE pipe) and capable of rotating as the tendon rolls over them during installation (Figure 9b).

(a) Pulling Bundled Strand into Tendon Anchor

(b) Strand Supports

Figure 9 — (Source: Dywidag)

In some cases, the epoxy coating can be damaged during installation to a level requiring repair. Damaged sections, which typically appear lighter in color and rough textured, are visually obvious due to the uniform, glossy appearance of the as-supplied product. Visual inspection is typically sufficient to identify damaged sections for further inspection if the outer perimeter of the tendon is easily accessible or visible, but a dry-type spark holiday detector can also be used to search for damaged sections on the exterior of an installed tendon. These types of detectors work by finding an electrical ground (i.e. severe loss of thickness or exposed steel). Once a damaged section is located, the inspector can then assess if a repair is required or not. If steel has been exposed, repair is automatically required. If the damage has only removed some of the epoxy coating (i.e. no exposed steel), then a portable magnetic thickness gauge can be used to verify the remaining coating thickness. Sharp or uneven coating damage surfaces should be flattened by an instrument like a file, so the thickness gauge can properly measure the residual thickness. The minimum thickness allowed per ASTM A882 is 15 mils (0.38 mm). This should be the standard used in the field to evaluate whether a damaged section requires repair or not. For reference, see reports FHWA-RD-74-18 and FHWA/TX-11/0-4562-3for additional information. This repair shall be carried out using an epoxy system complying with the ECS manufacturer's submitted repair procedure. Figure 10 shows the mixing of a two-part epoxy repair kit, application of the epoxy repair material, and heated curing of the epoxy repair material.

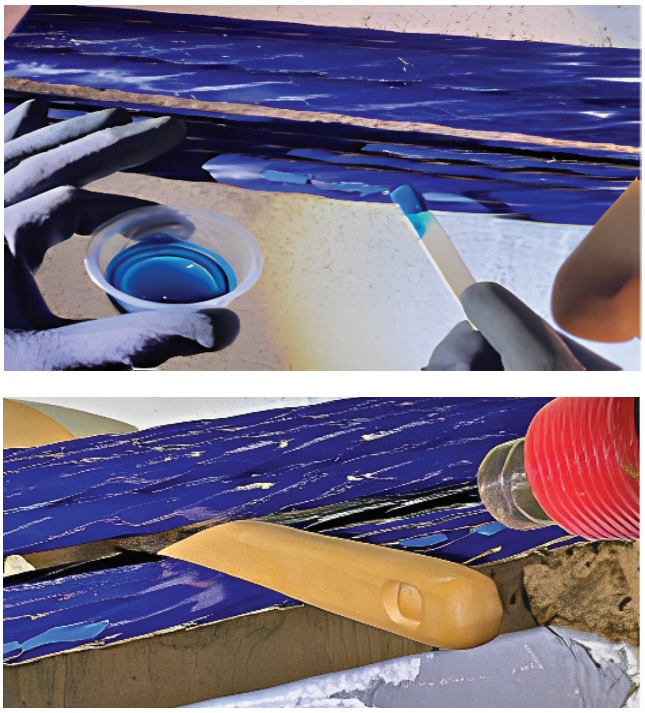


Figure 10 — Epoxy Strand Repair: Mixing Epoxy (Top), Applying Epoxy (Middle), & Curing Epoxy (Bottom) (Source: Sumiden Wire)

CONCLUSION

The use of un-ducted external post-tensioning with ECS presents enhancements to bridge durability, maintenance, and inspectability. This publication provides guidance on the design considerations, system qualifications, components, and installation processes necessary for successful implementation. Sample special provisions are included in Appendix A for reference.

The use of ECS also presents an opportunity for long-term monitoring of the tendon. *FHWA Tech Brief, Long-Term Monitoring of Post-Tensioning Tendon Force Using Optical Fiber Technology (FHWA Publication No.: FHWA-HIF-24-085)* can be consulted for further information on the use of this technology.

APPENDIX A - SPECIAL PROVISIONS FOR EPOXY-COATED PC STRAND UN-DUCTED EXTERNAL TENDONS

1. Prestressing Steel

The base prestressing steel is typically 0.60-inch diameter, Grade 270, low-relaxation seven-wire strand conforming to the requirements of ASTM A416/A416M "Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete" except for the relaxation property as defined below in Section 2.0 Epoxy-coated strand (ECS). Other sizes and grades can be used.

2. Epoxy-coated strand (ECS)

2.1. General

2.1.1. ECS shall conform to ASTM A882/A882M, "Standard Specification for Filled Epoxy-Coated Seven-Wire Prestressing Steel Strand." This standard defines the coating properties and provides a higher allowed maximum relaxation value than the one specified in ASTM A416.

2.1.2. ECS shall not be used in an installed location directly exposed to sunlight without polyethylene coating or some other form of protection against UV exposure.

2.2. Quality

2.2.1. Holidays or damage on ECS shall be repaired by using patching material designed for ECS in accordance with ASTM A882/A882M. It shall be verified that repaired spots or sections with the patch material shall meet the requirements specified in ASTM A882/A882M prior to its use.

2.3. Handling and storage

2.3.1. ECS shall be properly protected and handled so as not to damage the coating.

2.3.2. Lifting the spool (see 2.3.3) with a device contacting the epoxy coating should be avoided to prevent coating damage. Lifting the spool by contacting the flanges or via a contacting the flanges or via a shaft through the center bore is preferred. If lifting by contacting the flanges, care should be taken to avoid damaging or deforming the flanges.

2.3.3. ECS strands shall be spooled on reels for ease of shipment and handling at the jobsite. Each ECS spool shall be wrapped with a manufacturer-approved material or protected by other manufacturer approved methods. The wrapping shall also ensure protection of the ECS from damage and have no adhering foreign matter or

damage to the epoxy coating material. Reels shall be covered with an ultraviolet-resistant cover to protect the epoxy coating from direct sunlight exposure.

- In case of a metal spool, the metal surface shall be properly covered with softer materials so that ECS does not directly contact the metal surface.
- Reel-less packaging can be applied if it is properly packaged with protection for coating damage prevention.

2.3.4. ECS spools should be stored indoors to avoid direct sunlight (UV exposure), physical damage to the coating, and adherence of foreign materials on the epoxy coating. If ECS spools need to be stored outdoors due to jobsite conditions, storing spools under a canopy or a roof is recommended in addition to the proper packaging on the spool.

2.3.5. Packaging materials on the spool should be removed right before uncoiling or installing ECS.

2.3.6. UV exposure should be within the limits established in Section 5 Installation during ECS uncoiling or installation.

3. Post-Tensioning System (PTS) Testing and Components:

3.1. Testing

3.1.1. For acceptance and approval of a PTS, the components and system testing shall be witnessed and certified by an independent testing laboratory as specified in PTI/ASBI M50.3-19(24) Specification for Multistrand and Grouted Post-Tensioning, Section 4.4. Successful completion of the following PTS system tests is required to be performed using ECS. For the tested systems, compliance with material properties and dimensions (including tolerances) declared for the tested system shall be documented. Other PTS qualification tests specified by PTI/ASBI M50.3-19(24) are required, although may be performed using bare strand or ECS. A change in wedge design and/or wedge plate design would necessitate performance of the full-scale tests in Sections 3.1.1 and 3.1.2. as per PTI/ASBI M50.3-19(24) Sections 4.4.1(1) and 4.4.1(3) Post-tensioning Anchorages.

3.1.2. Perform fatigue testing of anchorages in accordance with EAD160004-00-0301, Section 2.2.2, where the tendon should be subjected to two million (2,000,000) cycle fatigue loading with upper stress of 65% GUTS and stress amplitude of 11.6 ksi (80 MPa) and shall meet the acceptance criteria. For the tested systems, compliance with material properties and dimensions (including tolerances) declared for the tested system shall be documented.

3.1.3. A change in material properties and dimensions, including a modification of declared strand epoxy coating thickness, for the materials used in the initial Qualification testing in 3.1.1 and 3.1.2 above would require repetition of tests.

3.1.4. System leak tightness tests shall be completed for the sealed and ducted sections. In case of grouting injection (see Figure 3.2), the entire anchorage including the sealing device should be tested as per fib Bulletin 75 – Annex B.1 (for PL2). Test setup must be modified to accommodate for the presence of ECS strands. In case of gel injection (see Figure 3.1), the entire anchorage including the sealing device should be tested as per PTI DC45.1-18, Section 4.1.6.1 “leak test”, with the exception that the specimen is not previously subjected to a fatigue test.

3.2. Anchorage Body

3.2.1. PTS anchorage components including trumpets shall conform with PTI/ASBI M50.3-19(24).

3.3. Corrugated/Smooth Duct:

3.3.1. For the portion of the tendon in the anchorage areas, use corrugated plastic duct meeting the requirements of PTI/ASBI M50.3-19(24), Section 4.3.5.2, Corrugated Plastic Duct or smooth duct meeting the requirements of PTI/ASBI M50.3-19(24), Section 4.3.5.3, Smooth HDPE Duct.

3.3.2. For the portion of the tendon at deviators, use smooth duct meeting the requirements of PTI/ASBI M50.3-19(24) Section 4.3.5.3, Smooth HDPE Duct.

3.4. Permanent Protection Caps:

3.4.1. Use permanent protection caps meeting the requirements of PTI/ASBI M50.3-19(24).

3.5. Heat Shrink Sleeves:

3.5.1. If used, heat-shrink sleeves shall meet the requirements of PTI/ASBI M50.3-19(24). Install heat-shrink sleeves using procedures and methods in accordance with the manufacturer’s recommendations.

3.6. Sealing Device:

3.6.1. A sealing device should be added so the gel or grout can be retained in the anchorage area. (Refer to Figures 3.1 and 3.2)

3.6.1.1. Gel (a thixotropic, water-blocking compound based on highly refined mineral oil, cold filling) materials

with anti-corrosive properties shall be applied to the anchorage section. Corrosion inhibiting material shall be flexible with ability to fully fill the anchorage section and the deviation section connected to the anchor. Gel corrosion protection performance must be proven to meet the requirements set in PTI M10.2-24, Table 2.2.2.1, or equivalent.

3.7. Anchorages: Corrosion inhibiting measures (e.g. grouting, gel, etc.) shall be applied to the anchorage sections.

3.8. Inlets and vents:

3.8.1. Inlets and vents for grout or gel shall be properly located to prevent internal voids.

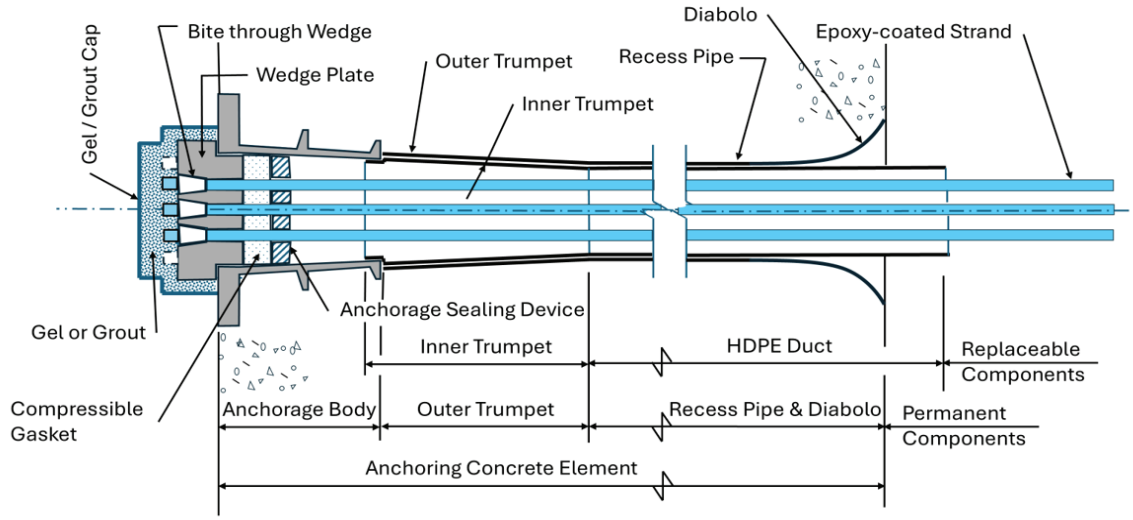


Figure 3.1 — Post-tensioning Anchorage Filling Cap Area

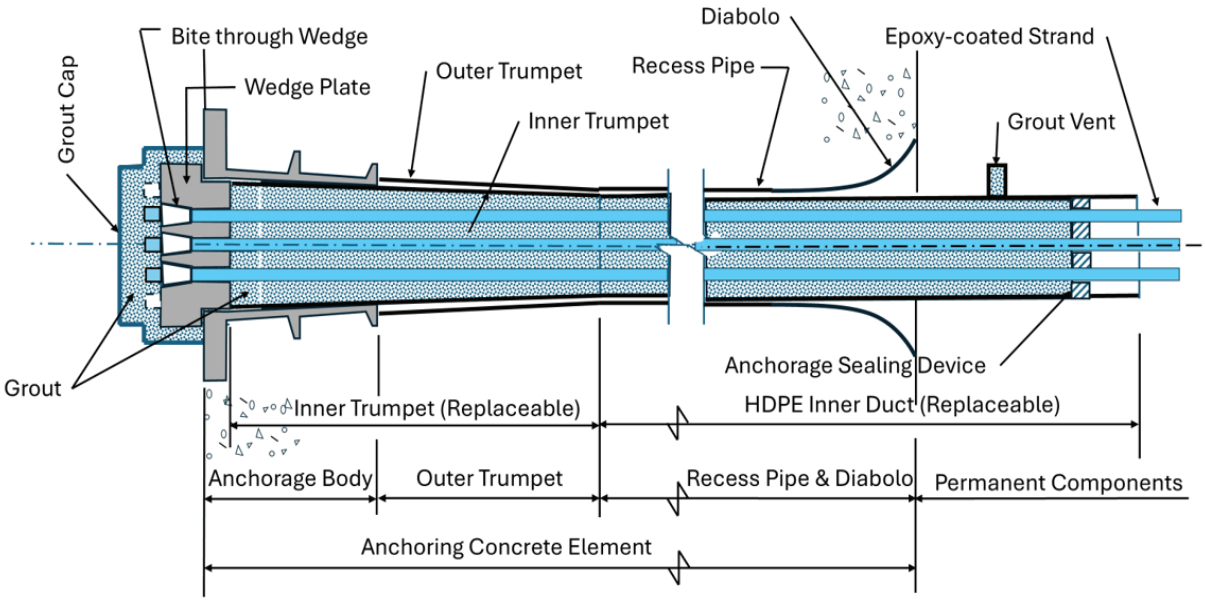


Figure 3.2 — Post-tensioning Anchorage Filling Cap and Partial Length of Duct

4. Designs

4.1. Anchorage and seating loss

4.1.1. Special anchorage designed for ECS shall be used for stressing and for anchoring.

4.1.2. Wedge seating loss specified by manufacturer or as measured by the stressing contractor shall be used for pre-stressing force calculation.

4.2. Elastic modulus

4.2.1. Elastic modulus of ECS can be regarded as the same as bare strand.

4.3. Relaxation

4.3.1. Maximum allowed 1,000-hour relaxation losses for ECS are slightly higher than for bare strand due to the thermal effects of the epoxy-coating process on the steel strand.

4.3.2. Maximum relaxation losses shall be in accordance with ASTM A882-26.

4.4. Deviations

4.4.1. Radius: Minimum radius at deviators (based on the center of the deviation pipe) shall be as follows:

Tendon Size	Minimum Radius at Deviators (feet)
7-0.6”	9.8
12-0.6”	9.8
15-0.6”	9.8
19-0.6”	9.8
22-0.6”	11.5
27-0.6”	11.5
31-0.6”	13.1
37-0.6”	13.1

Deviator fretting fatigue tests have been performed in Japan (JSCE-E 734-2013) for tendon sizes down to the 19-0.6” size at a radius of 9.8 ft; therefore, this is the smallest radius recommended in the table above. To utilize a smaller radius than specified by this article, the testing specified by European Assessment Document EAD160004-00-301, Section 2.2.6 and Annex C5 for plastic duct deviation / deflection (limits) shall be performed to verify the adequacy of the proposed details.

4.4.2. Protection: HDPE smooth pipe conforming to PTI/ASBI M50.3-19(24) article 4.3.5.3 shall be installed at each deviator for damage prevention on ECS. The diameter of the HDPE smooth pipe shall have an inner diameter as specified in the table. The HDPE smooth pipe shall extend past the deviator face by greater than 50% of the theoretical tendon elongation, and not less than 6-inches.

Tendon Size	HDPE Smooth Pipe Inner Diameter (Inch)
7-0.6”	3.0
12-0.6”	3.5
15-0.6”	4.5
19-0.6”	4.5
22-0.6”	5.0
27-0.6”	5.0
31-0.6”	5.5
37-0.6”	5.5

4.5. Protection for free-length of in-place tendons

4.5.1. Protection on ECS external tendons is not required when the tendons are installed inside a box girder without any possibility of direct/indirect sunlight exposure to the ECS.

Commentary: To allow for visible inspection of ECS during construction and during the bridge’s service life, ducts/pipes are not to be placed along the tendon length for the portion of tendons outside deviators/diaphragms, unless otherwise noted as required in the contract documents.

4.5.2. Any external tendons outside the girder require protective measures (e.g. HDPE coating) on ECS to avoid deterioration of the epoxy coating due to sunlight (UV exposure) or damage from physical impacts.

5. Installation

5.1. General

5.1.1. Preventative measures against coating damage shall be taken. Exposure to sunlight should be minimized and long-term exposure in excess of 30 days to sunlight

(UV exposure) shall be avoided during transportation, storage, installation, and stressing. If ECS is left exposed for over 30 days, this strand should be re-tested to ensure compliance with ASTM A882 adhesion tests before being used.

5.1.2. Installation and stressing shall be performed at no lower than 14°F.

Commentary: Generally, plastic materials have reduced flexibility at lower temperatures. There are more risks of epoxy coating cracking of ECS by dynamic strain during handling under low temperature. It has been confirmed that there was no problem on epoxy coating during some experiments down to 14°F.

5.2. Pre-installation inspection

5.2.1. When ECS is uncoiled, the strand or wire shall lay straight within a specified offset from a theoretical centerline in any 6-ft. of length. Sharp kinks or short radius bends (less than the reel radius) shall be cause for rejection.

Commentary: Sharp kinks or short radius bends produce shear stresses at these areas and result in reducing the service life of strands or wires. Experience indicates that the offset of ECS can be more than 4 in. in 6 ft. (101.6 mm in 1.83 m). This is due to a set in the epoxy and does not affect the properties of the strand. If a lesser offset is required, the Contractor should discuss special reel/pack dimensions and other alternatives with the strand supplier.

5.3. Quality control program - As a minimum, the Quality Control Program shall include the following items:

- Packaging and shipping for ECS and all protective materials.
- Records for traceability and shelf life of all materials.
- Mill certifications.
- Inspection of materials to ensure conformance that materials are undamaged as they are installed in the structure.
- Limitations on storage and handling, including time periods for storing materials, temperature and humidity limitations for materials, temporary corrosion protection, and any limitations on temporary storage or protection that shall be permitted to affect performance.
- Coiling limitations for materials subject to set or plastic deformations of ECS.
- Limitations on coatings, repair of coating damage, and supplemental protection for ECS.

5.4. Anchorage

5.4.1. Bite-through wedges designed for ECS are the required anchorage method.

5.4.2. All anchorages shall be inspected and free from damage, dirt, and rust.

5.4.3. Installed anchorages shall be properly protected to prevent damage, dirt, and rust if anchorages need to be installed prior to installing the ECS.

Commentary: Damage, dirt, rust on taper at the wedge plate or wedges may cause slippage of ECS during or after stressing.

5.4.4. Only use wedges of the correct size and type intended for use with ECS per the manufacturer's recommendations. Do not use wedges with teeth that are damaged or clogged with epoxy residue. This may result in strand slip and serious accidents.

5.5. Protective ducts at Deviators

5.5.1. Polyethylene ducts used for diabolo shall not be deformed during handling or casting concrete.

5.6. Transportation

5.6.1. ECS shall be carefully handled so that coating damage or deformations do not occur due to rubbing or impact to ECS during handling.

5.7. Storage

5.7.1. ECS shall be stored indoors as long as possible.

5.7.2. If ECS is stored outdoors, proper protective measures shall be applied to avoid coating damage, dust, or exposure to sunlight (UV exposure as specified in 5.1.1).

5.8. ECS installation

5.8.1. Proper equipment covered with protective material shall be used for strand/tendon uncoiling for coating damage prevention.

5.8.2. Care shall be taken when installing and stressing ECS to ensure the individual strands are not crossing each other.

5.8.3. The whole length of the installation path shall be properly protected with softer materials than epoxy (e.g., HDPE, fabric, wood) and observed during installation.

5.8.4. Deviation radius of ECS along the uncoiling or installation path shall be no less than 5 ft during installation. This is a much smaller radius than the minimum design radius recommended in Section 4.4.1. The reason for this smaller recommended radius is because the ECS is not bundled tightly together (as in a typical installed tendon), and each individual strand is flexible.

5.8.5. Tendons shall be installed by the pull method of a preassembled multi-strand bundle, unless other methods (i.e. pushing method or individual strand pulling) are specifically noted as permitted or required in the contract documents. A tendon installation plan shall be prepared and submitted for approval.

Commentary: Deviators ECS tendons are most commonly installed by pulling prefabricated multistrand bundles. They have also been installed using the strand-by-strand push or pull method; however, additional precautionary measures need to be taken to ensure strand alignment and mitigate strand damage.

5.9. Deviation fabrication and arrangement

5.9.1. Plastic materials (such as polyethylene ducts) shall be used at deviators, pier diaphragms, and anchorages for epoxy coating protection.

5.9.2. Deviators for ECS shall use a diabolo detail. The geometry of the diabolo shall follow the requirements shown in Figure 5.1. The deviation angle * shall not produce a radius less than the minimum radius specified in Section 4.4.1. The diabolo bell mouth angle** shall be greater than or equal to 3-degrees. The diabolo throat diameter shall provide a minimum ½-inch gap between the bottom of the duct and the bottom diabolo surface.
Diabolos may be constructed using permanent or removable forms. Ensure diabolos:

- Are sufficiently rigid to maintain their shape during handling, installation, and concreting;
- Provide a smooth surface with no kinks; and
- Are designed with an additional deviation angle of 3 degrees

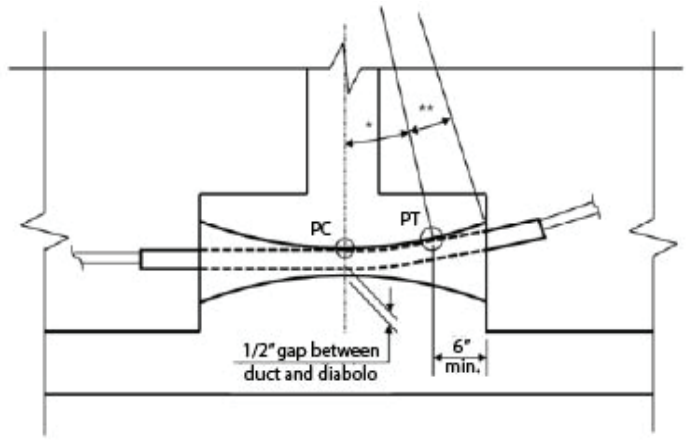
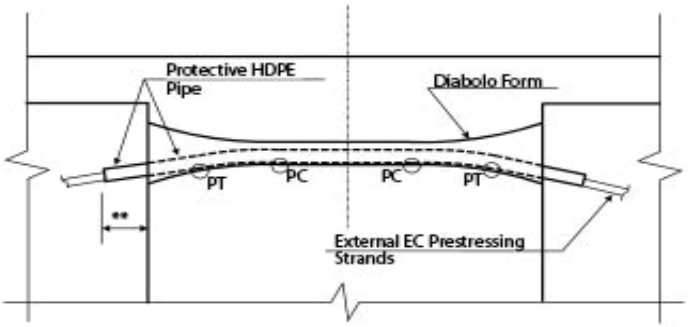


Figure 5.1 — Diabolo Geometry

5.9.3. The diablo form at pier diaphragms shall follow the requirements shown in Figure 5.2. The radius between the point of curvature (PC) and point of tangency (PT) shall not be less than the minimum radius specified in Section 4.4.1. The diablo bell mouth angle between the PT and diaphragm face shall be greater than or equal to 3-degrees. The diablo throat diameter shall provide at least a minimum 3/4-inch gap between the top of the duct and the top diablo surface and not vary along the throat tangent length between points of curvature (PC).



** HDPE duct shall extend past the diaphragm face greater than 50% of the theoretical tendon elongation, and not less than 6-inches.

Figure 5.2 — Diabolo Geometry at Pier Diaphragm

5.9.4. The diablo form at anchorages shall follow the requirements shown in Figure 5.3. The radius between the point of curvature (PC) and point of tangency (PT) shall not be less than the minimum radius specified in Section 4.4.1. The diablo bell mouth angle between the point of tangency PT and diaphragm face shall be greater than or equal to 3-degrees. The diablo throat diameter shall at least equal the outer diameter of the smooth HDPE duct. The tangent length from the anchorage face to the point of curvature (PC) shall meet or exceed PT manufacturers' requirement.

Post-Tensioning Anchorages without tendon profile change within the anchorage diaphragm shall utilize a 6-inch minimum extension of the HDPE duct beyond the bell mouth.

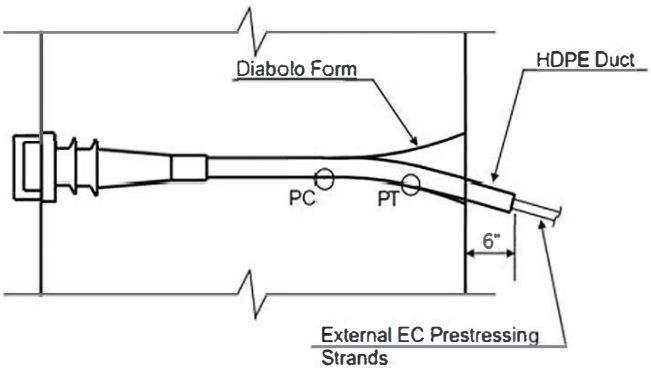


Figure 5.3 — Diabolo Geometry at Anchorage

5.10. Stressing

5.10.1. Multi-strand stressing is required to prevent coating damage, especially at the deviator sections.

5.10.2. Special stressing equipment including pulling (stressing) wedges designed for ECS are required.

- All post-tensioning systems and stressing equipment for ECS are required to execute verification tests for stressing at its development stage. Verification tests shall validate the number of re-grips with the same pulling (stressing) wedges and anchorage wedges to be used on the project.

5.10.3. ECS wedges and wedge teeth are typically larger than bare strand wedges. When stressing ECS, the wedges must have a longer space to travel out of the anchor pocket than bare strand requires to prevent damaging the coating. In some cases, the distance needed can be 2x the distance for bare strand. Because this detail on anchorage systems can vary by supplier, each system should be evaluated to ensure sufficient distance is installed to prevent coating damage.

5.10.4. Both pulling (stressing) and anchorage wedges shall be inspected. Wedges with damage (cracking, flattened teeth, etc.), dirt, or rust shall not be used. Also, epoxy residue clogged between the teeth should be removed prior to use.

Commentary: Using the wrong pulling (stressing) wedges (e.g. wrong size, bare strand pulling (stressing) wedges, or other incompatible pulling (stressing) wedges), ones with damaged teeth or teeth clogged with epoxy residue may cause issues such as strand slippage or unequal forces among strands and lead to serious incidents.

5.10.5. At re-stressing (when ECS needs to be stressed multiple times to reach the final force), do not grip where it was previously gripped.

Commentary: Determine in advance the maximum re-stressing times to safely pull ECS without inspecting wedges prior to stressing work by performing demonstration stressing tests. Because bite-through ECS wedges must penetrate the epoxy coating to grip the steel and because there are fewer teeth (compared to a bare strand wedge) on a bite-through wedge, the condition of the teeth must be confirmed to be in good condition prior to stressing.

5.10.6. It is critical to verify the accuracy of the established seating loss during the stress operation, as this value must be factored into the calculations for both friction and elongation. Friction seating values can be up to 7/8” (22 mm).

5.10.7. After the completion of stressing each tendon, it shall be verified that all anchor wedges (the wedges used in the anchor plate) are properly anchored and no coating damages occurred on the extra length of ECS extending beyond the wedge plate except wedge bite marks. All epoxy residue remaining between pulling (stressing) wedge teeth (the wedges used in the strand jack) shall be removed, and any damaged pulling (stressing) wedges (cracking, flattened teeth, etc.) shall be replaced prior to subsequent use.

5.10.8. If the stressing force is less than 60% of the minimum specified tensile strength of the strand, it is advisable to implement a post-blocking procedure for the wedges. This process is akin to power seating, but it occurs after the stressing jack has been removed and the prestressing force has been transferred from the jack to the anchorage wedges. Post-blocking ensures that the anchorage wedges have fully penetrated the epoxy coating. As the post-blocking force is typically greater than that required for power seating and due to potential slight centering alignment variances between the strand and anchor pocket, this procedure is conducted after the stressing force from the jack has been released. The exact force necessary for post-blocking the wedges can vary depending on the post-tensioning equipment being used; therefore, it is essential for the PT supplier to confirm that the wedges are adequately penetrating the steel at the chosen post-blocking force.

5.10.9. After stressing, cut extra length of strands with abrasive grinders, saws, cutters, or other mechanical means. Torches or flame cutting of strands shall not be permitted.

5.10.10. Appropriate procedures shall be planned and taken at anti-corrosion material injection into the anchorage section to avoid internal voids considering material properties.

5.11. System Drawings

Submit post-tensioning system drawings showing all components required for the tendon installation, both temporary and permanent (to include part numbers as appropriate). Define the nominal geometry and material composition of all components to be used.

As a minimum, show all applicable:

- Wedge plates, wedges, bearing plates, trumpets, couplers, and local zone reinforcement;
- Permanent grout caps and other sealing devices with installation accessories;
- Ducts, couplers, and typical connection details for items inside the concrete and installed in deviators;
- Typical details for all vents and inspection points in the anchorages;
- Duct inner diameter (ID) and outer diameter (OD) (major and minor) or other defining internal and external dimensions;
- Tendon types and sizes;
- Tendon "Z" factors (center of gravity of strand [cgs] offsets) for all duct and tendon size combinations;
- Friction coefficient and wobble details;
- Duct minimum radius of bending and maximum support spacing;
- Methods for supporting all hardware;
- Minimum stressing tails for all tendon types;
- Minimum concrete blockout dimensions for equipment access and concrete cover;
- System seating losses (anchor set);
- Minimum concrete strength for stressing;
- Newly developed features not mentioned previously;
- Details for diabolo forms.
- Repair procedure for epoxy coating damage.

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Strength in Concrete

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