SECTION 960
POST-TENSIONING COMPONENTS

960-1 Description.

This Section covers all post-tensioning (PT) components remaining in a completed structure, including temporary erection PT left in-place and permanent PT for design capacity.

Manufacturers seeking approval of PT systems for inclusion on the Structures Design Office (SDO) list of Approved Post-Tensioning Systems must use materials and components meeting requirements of this Section and Section 462. Submit a complete PT System Application Package including component drawings, system drawings, and test reports from a certified laboratory (or laboratories), as defined in 960-3.1, to the SDO for review, acceptance and inclusion on the list of Approved Post-Tensioning Systems.

Any marked variations from original test values or any evidence of inadequate field performance of a PT system, will result in the PT System being removed from the list of Approved Post-Tensioning Systems.

960-1.1 Material References: Meet the requirements of this Section and the following:

Epoxy Compounds*	Section 926
Bar (post-tensioning)	Section 933
Duct Filler for Post Tensioned Structures*	Section 938
Reinforcing Steel (mild)	Section 415
Parallel Wire (post-tensioning)	Section 933
Strand (post-tensioning)	Section 933

*Use products listed on the Department's Approved Product List (APL).

960-2 Component Standards.

All PT system components must be materials compatible with the filler material and installation process used to encapsulate the tendons. The component materials must not chemically degrade during the design life of the structure.

Substitution, modification, or deletion of components of PT systems as shown on the SDO website for Approved Post-Tensioning Systems, excluding local zone reinforcement, is not permitted. Inclusion of all possible subcomponents is required for PT system and component testing; however, subcomponents of approved systems may be eliminated from final installations based on project specific requirements, provided all component-to-component interface hardware are included as necessary to maintain connections and PT system integrity.

Provide only PT systems utilizing tendons completely encapsulated in grout or flexible filler filled anchorages and ducts. Do not use systems transferring prestress force by bonding prestress steel strand directly to concrete. Embedded anchorages for bars are permitted. Strand or strand-tendon couplers are not permitted.

Stamp all components of a PT system with the suppliers name, trademark, model number, and size corresponding to catalog designation.

All miscellaneous hardware components, including but not limited to splices, joints, duct couplers, connections, inlets, outlets, drains, ports, valves, and plugs, are part of approved PT systems.

960-2.1 Anchorage Assembly:

1. Construct anchorages from ferrous metal.

2. Anchorages shall develop at least 96% of PT steel actual ultimate strength when tested in an unbonded state, without exceeding anticipated anchor set.

3. Average concrete bearing stress shall be in compliance with AASHTO LRFD Bridge Design Specifications and AASHTO LRFD Bridge Construction Specifications.

4. Test anchorages with typical local zone reinforcement shown in system drawings.

5. Test anchorages in accordance with AASHTO LRFD Bridge Construction Specifications, or the Guideline for European Technical Approval of Post-Tensioning Kits for Prestressing of Structures (ETAG-013, June 2002 edition) with the exception that the design concrete strength used in the testing will be 6,500 psi. For anchorages that will be used for tendons with flexible filler, test anchorages in accordance with ETAG-013 Section 6.1.2-I.

6. Anchorages with grout or flexible filler outlets shall be suitable for inspection from either top or front of anchorage. Anchorages may be fabricated to facilitate both inspection locations or may be two separate anchorages of the same type, each providing singular inspection entry locations.

7. Geometry of grout and flexible filler outlets must facilitate access for borescope inspection directly behind wedge plate using a straight 3/8 inch diameter drill bit.

8. Ferrous metal components of an anchorage that are to be embedded in concrete shall be galvanized in accordance with Section 962. Other anchorage assembly components, including wedges, wedge plates, and local zone reinforcement need not be galvanized.

9. All anchorages shall have a permanent vented anchorage cap bolted to the anchorage.

960-2.1.1 Trumpets:

1. Trumpets associated with anchorages shall be constructed from ferrous metal galvanized per ASTM A123, polypropylene plastic, or polyolefin.

2. Trumpet thickness at transition location shall be the thickness of the duct or greater.

960-2.1.2 Wedges and Wedge Plates:

1. Wedge plate shall be ferrous metal.

2. Wedge plates must have centering lugs or shoulders to facilitate alignment with bearing plate.

3. For longitudinal tendons greater than four strands, design system with separate wedge plate and anchorage plate.

960-2.2 Filler Containment Assembly:

960-2.2.1 Duct and Pipe:

1. Use plastic duct, steel pipe, or a combination of plastic duct and steel pipe in accordance with this Section.

2. Ducts shall be manufactured by a seamless fabrication method. Fabricate all duct splices to prevent kinks during all phases of construction.

3. Do not alter the natural duct color that results from UV protected polymer.

4. Corrugated ferrous metal ducts are prohibited.

960-2.2.1.1 Corrugated Plastic Duct:

1. PT systems with duct injected with grout shall use corrugated polypropylene plastic material except where steel pipe is required.

2. Furnish ducts with minimum wall thickness as follows:

Table 2.2.1.1-1: Corrugated Plastic Duct Minimum Wall Thicknesses		
Duct Shape	Duct Diameter	Duct Wall Thickness
Flat	Any Size	0.08 inch
Round	0.9 inch	0.08 inch
Round	2.375 inch	0.08 inch
Round	3.0 inch	0.10 inch
Round	3.35 inch	0.10 inch
Round	4.0 inch	0.12 inch
Round	4.5 inch	0.14 inch
Round	5.125 inch	0.16 inch
Round	5.71 inch	0.16 inch

960-2.2.1.2 Smooth Plastic Duct:

1. PT systems with duct injected with flexible filler shall use smooth plastic duct.

2. Duct shall be polyethylene resin material.

3. Duct shall have a maximum dimension ratio (DR) of 17 as established by either ASTM D3035 or ASTM F714, as appropriate for manufacturing process used.

4. Duct shall have a minimum pressure rating of 125 psi.

960-2.2.1.3 Steel Pipe: Steel pipes shall be ASTM A53, Type E, Grade B, Schedule 40 and galvanized in accordance with Section 962.

960-2.2.1.4 Minimum Internal Diameter:

1. For prestressing bars, duct shall have a minimum internal diameter of 1/2 inches larger than bar outside diameter, measured across deformations.

2. For prestressing bars with couplers, duct shall have a minimum internal diameter of 1/2 inches larger than largest dimension of the largest enclosed element.

3. For multi-strand tendons, ducts must have a minimum cross-sectional area 2-1/2 times PT steel cross-sectional area.

960-2.2.1.5 Connections, Fittings, and Tolerance:

1. Devices or methods for all duct connections (e.g., splices, joints, couplers, connection to anchorages), shall produce smooth interior alignment with no lips or kinks.

2. Use of tape is not permitted to join or repair duct, to make connections, or for any other purpose.

3. Use a reducer when adjacent sections of duct are directly connected to each other and the outside diameters vary more than plus or minus 0.08 inch.

4. Provide all connections that are external to the concrete with a minimum pressure rating of 150 psi.

5. Use heat shrink sleeves and circular sleeve couplers made from polyolefin or polypropylene material, or duct couplers made from polyolefin or polypropylene material with O-rings or seals to make connections between sections of corrugated plastic duct or between corrugated plastic duct and trumpets.

6. Use heat shrink sleeves and circular sleeve couplers made from polyolefin or polypropylene material to make connections between corrugated plastic duct and steel pipe.

7. Use heat shrink sleeves with or without circular sleeve couplers made from polyolefin or polypropylene material to make connections between corrugated plastic duct and anchorages with integral trumpets.

8. Use heat welding techniques, electrofusion duct couplers, or elastomer sleeves and stainless steel band clamps to make connections between sections of smooth plastic duct.

9. Use elastomer sleeves and stainless steel band clamps to make connections between smooth plastic duct and steel pipe.

10. Use welding or elastomer sleeves and stainless steel band clamps to make connections between sections of steel pipe that are external to the concrete.

11. Use welding, elastomer sleeves and stainless steel band clamps or heat shrink sleeves and circular sleeve couplers made from polyolefin or polypropylene material to make connections between steel pipe and trumpets that are internal to the concrete.

12. Use elastomer sleeves with a minimum wall thickness of 3/8 inches and reinforced with a minimum of four ply polyester reinforcement. Use a 3/8 inch wide stainless steel power seated band and clamps on each end of the elastomer sleeves to secure the sleeves to plastic ducts or steel pipes. Seat the bands with a 120 pound force prior to clamping them in place.

960-2.2.1.6 Segmental Duct Couplers:

1. Include segmental duct couplers for permanent internal PT systems at joints between match cast precast segments.

2. Use “O”- rings or compression seals between adjoining sections of segmental duct couplers.

3. Plastic duct couplers shall be polyolefin or polypropylene material.

4. Metallic components shall be stainless steel per 960-2.4.3.

5. Segmental duct couplers shall mount perpendicular to the bulkhead at segment joints and provide for duct alignment.

6. Segmental duct couplers shall be able to receive duct at an angle of 6 degree deviation from perpendicular.

7. Segmental duct couplers must be able to accommodate angular deviation of duct without tendon strands touching duct or coupler on either side of segment joint.

8. Ducts for prestressing, used exclusively for temporary erection PT that is to be removed from structure, are not required to be coupled across segment joints.

960-2.2.1.7 “O”-Rings:

1. “O”-rings with cross section diameters less than or equal to 0.25 inches and compression seals with thicknesses less than or equal to 0.25 inches for use with segmental duct couplers, anchorage caps and other similar components shall conform to the requirements of Table 2.2.1.7-1.

Table 2.2.1.7-1 "O"-Ring and Compression Seal Material Properties (cross section diameter or thickness ≤ 0.25 in)	
Mechanical Properties	
Shore hardness, ASTM D2240	50-75
Ultimate elongation %, ASTM D412	250% min.
Tensile strength, ASTM D412	1400 psi min.
Accelerated Testing	
Thermal Deterioration 70 hours @ 257° F, ASTM D573	
Change in tensile strength	± 30%
Change of elongation	-50%
Change of hardness	± 15 points
Compression Set Method B 22 hours @ 257° F, ASTM D395	50%
Volume change due to absorption of H_2O, Method D, for 70 hours @ 212°F, ASTM D 471	+ 10%
Environmental Resistance	
Ozone Resistance Exposure Method B, ASTM D1171	Pass
Low Temp. Non-brittle after 3 Min. @ -40°F, ASTM D2137	Pass

2. “O”-rings with cross section diameters greater than 0.25 inches and compression seals with thicknesses greater than 0.25 inches for use with segmental duct couplers, anchorage caps and other similar components, shall conform to the requirements in Table 2.2.1.7-1 with the additions and modifications in Table 2.2.1.7-2.

Table 2.2.1.7-2 “O”-Rings and Compression Seal Material Properties (cross section diameter or thickness > 0.25 in)	
Mechanical Properties	
Shore hardness, ASTM D2240	30-60
Tensile strength, ASTM D412	600 psi min.
Compression Set Method B 22 hours @ 257° F, ASTM D395	60%

3. **Compression Force** - Maximum force to compress an “O”-ring or compression seal to its final compressed position shall not be greater than 25 psi times the area encircled by “O”-ring or seal.

4. **Voided Area** - Compression seals must accommodate material flow within its own cross sectional area by using a hollow or voided design.

960-2.2.1.8 Heat Shrink Sleeves:

1. Heat shrink sleeves shall have unidirectional circumferential recovery and be sized specifically for duct size being coupled.

2. Use irradiated and cross linked high density polyethylene backing for external applications and linear-density polyethylene for internal applications.

3. Use adhesive with the same bond value to steel and polyolefin plastic materials.

4. Heat shrink sleeves shall have an adhesive layer that meets the requirements of the following table:

Table 2.2.1.8-1 Heat Shrink Sleeve Adhesive Layer Minimum Requirements

Property	Test Method	Minimum Requirements	
		Internal Application	External Application
Minimum Fully Recovered Thickness		92 to 126 mils	111 mils
Peel Strength	ASTM D 1000	29 pli	46 pli
Softening Point	ASTM E 28	162°F	216°F
Lap Shear	DIN 30 672M	87 psi	58 psi
Tensile Strength	ASTM D 638	2,900 to 3,480 psi	3,480 psi
Hardness	ASTM D 2240	46 to 48 Shore D	52 Shore D
Water Absorption	ASTM D 570	Less than 0.05%	Less than 0.05%
Color		Yellow or Black	Black
Minimum Recovery	Heat Recovery Test	33% to 58%	23%
Operating Temperature		125°F	150°F

5. Install heat shrink sleeves using procedures and methods specified in the manufacturer's instructions.

960-2.2.2 Attachments:

960-2.2.2.1 Anchorage Caps:

1. Provide permanent anchorage caps made of stainless steel, nylon, polyester, or Acrylonitrile Butadiene Styrene (ABS).

2. Seal Anchorage cap with "O"-ring seals or precision fitted flat gaskets placed against the bearing plate.

3. Place a vent hole of 3/8 inch minimum diameter suitable for filler venting and inspection of the content inside the anchorage cap from the top or front of the anchorage cap as appropriate (e.g. anchorage caps not accessible after filler injection must have a vent at the top of the cap). Anchorage caps may be fabricated to facilitate both inspection locations.

4. Anchorage caps shall have a minimum pressure rating of 150 psi.

5. Stainless steel bolts shall be used to attach cap to anchorage.

6. Certified test reports documenting steel chemical analysis shall be submitted when stainless steel anchorage caps are used.

960-2.2.2.2 Inlets, Outlets, Drains, Ports, Valves, and Plugs:

1. Provide permanent inlets, outlets, drains, ports, valves, and threaded plugs made of nylon, polyolefin materials, or stainless steel.

2. All inlets, outlets, drains and ports shall have pressure rated mechanical shut-off valves or plugs. Mechanical shut-off valves must be 1/4 turn ball valves.

3. Inlets, outlets, drains, ports, valves, and plugs shall have a minimum pressure rating of 150 psi.

4. Inlets, outlets and ports shall have a minimum inside diameter of 3/4 inches for strand and 3/8 inches for single bar tendons and four-strand ducts.

5. Drains shall have a minimum inside diameter of 3/8 inches. Locate drains, and inlets and outlets serving as drains, at the bottom of the duct cross section.

6. Dual in-line mechanical shutoff valves are required for vertical PT systems.

7. Specifically designate temporary items, not part of the permanent structure, on PT system drawings.

960-2.3 Steel Reinforcing:

960-2.3.1 Mild:

1. Reinforcing steel shall conform to Section 415 and Section 462.

2. Test typical local zone reinforcement for compliance with AASHTO LRFD Bridge Design Specifications and AASHTO LRFD Bridge Construction Specifications, as applicable. Include reinforcement details in system drawings submitted for system approval.

960-2.3.2 Prestressing:

960-2.3.2.1 Strand: Prestressing strands shall be in accordance with Section 933.

960-2.3.2.2 Bar:

1. Prestressing bars shall be in accordance with Section 933.

2. Bar couplers shall be in compliance with AASHTO LRFD Bridge Design Specifications and AASHTO LRFD Bridge Construction Specifications.

3. Test bar couplers in accordance with AASHTO LRFD Bridge Construction Specifications or the Guideline for European Technical Approval of Post-Tensioning Kits for Prestressing of Structures (ETAG-013, June 2002 edition). For bar couplers that will be used for tendons with flexible filler, test bar couplers in accordance with ETAG-013 Section 6.1.2-I.

4. Use only spherical nuts to anchor bars at bearing plates.

960-2.4 PT System Materials:

1. Use material specifications in this Section for all PT system components and subcomponents.

2. Use only virgin material for all non-ferrous components.

3. Test only samples taken from finished product as applicable.

960-2.4.1 Nylon: Use one of the following cell classes according to ASTM D5989:

1. S-PA0141 – weather resistant.

2. S-PA0231 – heat stabilized.

3. S-PA0401 – ultimate strength not less than 10,000 psi with UV stabilizer added.

960-2.4.2 Polyolefin: Conform to both of the following:

1. Contains antioxidants with a minimum Oxidation Induction Time (OIT) according to ASTM D3895 of not less than 20 minutes.

2. Remolded finished material has a minimum failure time of three hours when tested for stress crack resistance using ASTM F2136 at an applied stress of 348 psi.

960-2.4.3 Stainless Steel: Conform to the following:

1. ASTM A240 Type 316 - for metallic components other than bolts.

2. ASTM F593 Type 316 - for bolts.

960-2.4.4 Polypropylene: Conform to all of the following:

1. Non-colored, unfilled polypropylene according to ASTM D4101 with a cell class range of PP0340B44541 to PP0340B67884.

2. Contains antioxidants with a minimum Oxidation Induction Time (OIT) according to ASTM D3895 of not less than 20 minutes.

3. Contains a non-yellowing light stabilizer.

960-2.4.5 Polyethylene Resin: Conform to all of the following:

1. Meets requirements of ASTM D3350 with a minimum cell class of 445574C.

2. Contains antioxidants with a minimum Oxidation Induction Time (OIT) according to ASTM D3895 of 40 minutes.

960-2.4.6 Elastomer Sleeves: Conform to all of the following:

1. Meet requirements of ASTM D1171 using Ozone Chamber Exposure Method B (no cracks permitted under 2X magnification).

2. Manufactured using an elastic polymeric material that is compatible with concrete, the PT system components to which the sleeves will be attached, and the filler material and filler material installation process. Identify the applicable ASTM specifications that the sleeve material complies with.

960-3 System Pre-Approval Requirements.

960-3.1 Independent Testing: Use independent laboratories meeting the credentials described in this Section to perform all testing and to submit certified test reports for materials and components. Certification may be performed by a qualified independent laboratory outside of the United States, only if the facility is pre-approved by the State Materials Office.

Conform all testing procedures used for materials or components to applicable American Society of Testing and Materials (ASTM) and International Federation of Structural Concrete (fib) Specifications or as modified in this Section.

960-3.1.1 Material Laboratory: Test plastic components in a certified independent laboratory accredited through the laboratory accreditation program of the Geosynthetic Accreditation Institute (GAI) or the American Association for Laboratory Accreditation (A2LA).

960-3.1.2 Component and System Laboratory: Test individual components and the PT system as a whole witnessed by and/or in a certified independent laboratory audited by the AASHTO Materials Reference Laboratory (AMRL).

960-3.2 Testing Requirements:

960-3.2.1 Component and System Tests: Corrugated duct, smooth duct and all associated components that are used for both internal and external PT systems, e.g. couplers, anchorages, inlets, outlets, drains, ports, valves, plugs, etc., shall meet the requirements of fib Technical Report Bulletin 75 titled, Polymer-Duct Systems for Internal Bonded Post-Tensioning, Performance Level 2 (PL2), with modifications as shown in Table 3.2.1-1.

Table 3.2.1-1 Required Component and System Tests

Reference to fib Bulletin 75			Required Tests for each PT System Type[(1)]		
Procedures	Appendix	Test Description	Internal PT System	Internal PT System with	External PT System

Table 3.2.1-1 Required Component and System Tests					
Reference to fib Bulletin 75			Required Tests for each PT System Type[1]		
			with Grout	Flexible Filler	with Flexible Filler
Component Assessment	A.1	Dimensional requirement	Yes	No	No
	A.2	Stiffness of duct	Yes[2]	No	No
	A.3	Longitudinal load resistance	Yes	Yes	Yes
	A.4	Lateral load resistance	Yes	No	No
	A.5	Flexibility of duct system	Yes	Yes	No
	A.6	Leak tightness of duct system	Yes	Yes	No
	A.7	Concrete pressure on duct	Yes[3]	No	No
	A.8	Wear resistance of duct	Yes	No	No
	A.9	Wear resistance of duct under sustained load	Yes	No	No
	A.10	Bond behavior of duct	Yes	No	No
	A.11	Precast segmental duct coupler system	Yes[4]	Yes[4]	No
	A.12	Fracture resistance of duct	No	No	No
System Assessment	B.1	Leak tightness of anchorage-duct assembly	Yes[5]	Yes[5]	Yes[5]
	B.2	EIT performance of duct system	No	No	No
	B.3	EIT performance of anchorage-duct assembly	No	No	No
	B.4	Full scale duct system assembly	Yes[5][6]	Yes[5][6]	Yes[5][6]
	B.5	Leak tightness of assembled duct system	Yes[5][6]	Yes[5][6]	No

1. Yes = Test is required; No = Test is not required.
2. Do not preload strand into duct prior to testing.
3. Identify duct as meeting Performance Class I or II criteria.
4. Use an epoxy compound meeting the requirements of Section 926, Type AB.
5. Perform tests on the largest assembly and the smallest assembly for each family of PT systems. A family of PT systems is defined a group of PT strand/bar assemblies of various sizes using common anchorage devices and design.
6. For each test, use a PT system assembly consisting of at least one of each component and connection type required to install a tendon from anchorage cap to anchorage cap. For bar tendon systems, use between 15 and 50 feet of duct with a straight profile.

960-3.2.2 Filler Containment Assembly Pressure Test: In addition to the other testing specified in this Section, test all filler containment assemblies, i.e., anchorages, anchorage caps, inlets, outlets, drains, ports, valves, plugs, etc., as follows:

1. Assemble the anchorage and anchorage cap with all required filler injection attachments.

2. Seal the opening in the anchorage where the duct/trumpet connects.

3. Condition the assembly by maintaining a pressure of 150 psi in the system for three hours.

4. After conditioning, lock off the air supply to the assembly.

5. After lock off, the assembly must sustain 150 psi internal pressure for five minutes with no more than 15 psi, or 10%, reduction in pressure.

This test may be combined with the External Duct Systems Pressure Test for external PT systems.

960-3.2.3 External PT Systems Pressure Test: In addition to the other testing specified in this Section, test all external PT systems as follows:

1. Prepare a system assembly consisting of at least one of each component and connection type required to install a tendon from anchorage cap to anchorage cap using between 15 and 50 feet of duct with a straight profile.
2. Condition the assembly by maintaining a pressure of 100 psi in the system for three hours.
3. After conditioning, lock off the air supply to the assembly.
4. After lock off, the assembly must sustain 100 psi internal pressure for five minutes with no more than 10 psi reduction in pressure.

960-3.2.4 Vacuum Test for Internal and External PT Systems with Flexible Filler: In addition to the other testing specified in this Section, test internal PT systems with flexible filler and all external PT as follows:

1. Prepare a system assembly consisting of at least one of each component and connection type required to install a tendon from anchorage cap to anchorage cap using between 15 and 50 feet of duct.
2. Condition the assembly by maintaining a 90% vacuum in it for 1 hour.
3. After conditioning, lock off the air supply to the assembly.
4. After lock off, the assembly must sustain a 90% vacuum for 5 minutes with no more than a 10% loss of vacuum.

960-3.3 Standard Tendon Sizes: Develop and test PT systems for both internal and external applications that can accommodate the following Department standard tendon sizes that are used for designing and detailing:

1. Standard strand tendon sizes: 4, 7, 12, 15, 19, 27, and 31 strand tendons, each using 0.6 inch diameter strand. Systems using alternate anchorage sizes or 1/2 inch diameter strand that provide equivalent force to these standard sizes may be submitted for approval.
2. Standard bar tendon diameters: 1, 1-1/4, 1-3/8, 1-3/4, 2-1/2 and 3 inch diameter bars.

960-3.4 System Modifications: Contact the SDO for direction before attempting to change pre-approved PT system materials or components. Repeat all appropriate material, component, and entire system tests if any component of a pre-approved PT system is modified or replaced, excluding local zone reinforcement. Submit an updated application to the SDO containing test reports and revised system drawings for proposed modified systems.

960-3.5 Component Samples: Furnish all required material samples to laboratories for testing and to the Department as requested, at no cost to the Department.

960-3.6 Calculations, Drawings, and Certification: Show fully detailed drawings of all component configurations, connections, anchorages, inlets, outlets, drains, high point inspection port details, anchorage inspection details, permanent anchorage caps, application limits of the PT system, and installation procedures of components for approval and posting on the SDO's website for Approved Post-Tensioning Systems. Submit details of typical local zone reinforcement in system drawings signed and sealed by a Specialty Engineer. Indicate that all PT system components are stamped with the following:

1. Manufacturer's name
2. Trademark model number

3. Size corresponding to catalog description on PT system drawings.

Submit an application package cover letter signed by an officer of the PT system vendor certifying that the submitted PT system, as a whole and all of its individual components, meet or exceed all material and component/system requirements of this Section, as demonstrated by the submittal. Indicate in this certification that all testing required by this Section was performed by a certified independent laboratory (or laboratories), as defined in 960-3.1, and that all tests were performed to applicable ASTM and fib Specifications. Submit proof of current laboratory accreditation specifically indicating applicable accreditation categories related to PT systems. Submit all material and component certifications required throughout this Section.