462 POST-TENSIONING.
(REV 10-31-07) (FA 2-14-08) (7-08)

PAGE 567. The following new Section is added after Section 461:

SECTION 462
POST-TENSIONING

462-1 General.

462-1.1 Description: Furnish and install all post-tensioning systems and any other pertinent items necessary for the particular prestressing system used, including but not limited to ducts, anchorage assemblies and local zone reinforcement. Both temporary and permanent post-tensioning shall comply with the requirements of this Section. Furnish all components of a post-tensioning system, including steel pipes, from a single supplier. Prestressing steel can be obtained from any supplier.

Install prestressing steel, which may be strands or bars, through ducts in the concrete. Stress to a predetermined load and anchor directly against the hardened concrete. Grout ducts to fill all voids and install protection at end anchorages.

Submit shop and working drawings and manuals in accordance with this Specification and Section 5. The Contractor's Specialty Engineer shall produce, sign and seal all shop drawings related to post-tensioning.

462-1.2 Qualifications and Inspection: Perform all post-tensioning field operations under the direct supervision (crew foreman) of a qualified post-tensioning and grouting technician. Provide project personnel, a crew foreman and crew members in accordance with Section 105.

Conduct all stressing and grouting operations in the presence of the Engineer.

462-1.3 Shop Drawings: Prepare shop drawings to address all requirements stated in the plans and the requirements stated herein. Indicate the approved post-tensioning systems to be used. Show tendon geometry and locations complying with the plans and the limitations of the selected post-tensioning system. Show all inlets, outlets, high point outlet inspection details, anchorage inspection details and permanent grout caps, protection system materials and application limits.

462-1.4 Alternate Post-Tensioning Designs: Alternate designs using a post-tensioning scheme other than that shown on the plans may be submitted for the Engineer's approval provided that the proposed alternate scheme fulfills the following requirements:

(1) The prestress system is a type described in and meeting the requirements of this Specification.

(2) The net compressive stress in the concrete after all losses is at least as large as that provided by the post-tensioning shown on the plans.

(3) The distribution of individual tendons at each cross section generally conforms to the distribution shown on the plans.

(4) The ultimate strength of the structure with the proposed post-tensioning scheme meets the requirements of Section 5 of the "AASHTO LRFD Bridge Design Standard Specifications" and shall be equivalent to or greater than the service and strength limit states provided by the original design.

(5) Stresses in the concrete and prestressing steel at all sections and at all stages of construction meet the requirements of the Design Criteria noted on the plans.

(6) All provisions of the Design Criteria noted on the plans shall be satisfied.

(7) The Contractor fully designs and details, the elements where the alternate post-tensioning scheme is proposed to be used.

(8) The Contractor submits complete shop drawings including post-tensioning scheme and system, reinforcing steel, and concrete cover; and design calculations (including short and long term prestress losses) for the Engineer's approval.

(9) Any alternate post-tensioning system approved by the Engineer, which results in a change in quantity from that shown on the Contract Documents, will be paid based on the quantity actually used and accepted or the plan quantity, whichever is less, and at the unit bid price. If the approved alternate post-tensioning scheme or system is under a VECP (Value Engineering Change Proposal), the method of payment will be in compliance with the VECP agreement.

(10) Alternative post-tensioning shall be designed and sealed by the responsible Specialty Engineer.

462-1.5 Material Storage: Store all materials in a weatherproof building, shed or container until time of use.

462-2 Certification of Post-Tensioning Systems.

Use only post-tensioning systems that are approved by the State Structures Design Office. Manufacturers seeking evaluation of their post-tensioning systems must submit test results to the Structures Design Office and include certified test reports from an independent laboratory audited by AASHTO Materials Reference Laboratory (AMRL) which shows the post-tensioning system meets all the requirements specified herein. Test plastic components in a certified independent laboratory accredited through the laboratory accreditation program of the Geosynthetic Accrediation Institute (GAI) or the American Association for Laboratory Accreditation (A2LA). Certification of test reports may be performed by an independent laboratory located outside the U.S., if the independent laboratory is approved by the State Materials Office. If any component of the post-tensioning system is modified or replaced, the appropriate component test and entire system test, if needed, must be retested in accordance with the requirements herein and an updated application made to the Structures Design Office containing the test reports and revised system drawings. Before attempting to change post-tensioning system components contact the State Structures Design Office for direction.

Perform certification test for the plastic on a sample formed or cut from the finished product. Provide the Engineer with certification that the plastic from the duct sample complies with all requirements of the specified cell class, stress crack rating and the specified amount of antioxidant. Certify to the Engineer that the post-tensioning system being furnished is in compliance with all requirements stated herein.

Ensure that all components of a system are stamped with the suppliers name, trademark model number and size corresponding to catalog designation. Post-tensioning systems consist of an assembly of components for various sizes of strand or bars assembled and pressure tested. Post-tensioning systems will have to be developed and tested both internal (corrugated duct) and external (smooth duct) applications for each of the following:

Department standard tendon sizes for designing and detailing consist of 0.6 inch diameter strand in anchorages containing 4, 7, 12, 15, 19 and 27 strands; standard bar sizes from 5/8 to

1 3/4 inch diameter. Systems using alternate anchorage sizes and/or strands utilizing 1/2 inch strand and providing equivalent force to these standard sizes may be submitted for approval.

Prior to installing any post-tensioning hardware, furnish the Engineer with a certification from the PT supplier that the PT system chosen for the project meets the requirements of Section 462 and is a Department approved PT system along with a list of the system components and drawings. Upon completion of post-tensioning installation, provide a certification that the PT system supplied was installed without modification and met the requirements of the contract documents.

462-3 Definitions.

Anchorage Assembly: An assembly of various hardware components which secures a tendon at its ends after it has been stressed and, imparts the tendon force into the concrete.

Anticipated Set: The wedge set assumed to occur in the design calculation of the post-tensioning forces at the time of load transfer.

Bar: Post-tensioning bars are high strength steel bars, normally available from 5/8 to 1 3/4 inch diameter and usually threaded with very coarse thread.

Bearing Plate: Any hardware that transfers the tendon force directly into a structure or the ground.

Bleed: The autogenous flow of mixing water within or its emergence from, newly placed grout, caused by the settlement of the solid materials within the mass.

Coupler: A device used to transfer the prestressing force from one partial length prestressing tendon to another. (Strand couplers are not permitted.)

Duct: Material forming a conduit to accommodate prestressing steel installation and provide an annular space for the grout which protects the prestressing steel.

Family of Systems: Group of post-tensioning tendon assemblies of various sizes which use common anchorage devices and design. All components within the family of systems shall be furnished by a single supplier and shall have a common design with varying sizes.

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

Grout: A mixture of cementitious materials and water with or without mineral additives or admixtures, proportioned to produce a pumpable consistency without segregation of the constituents, when injected into the duct to fill the space around the prestressing steel.

Grout Cap: A device that contains the grout and forms a protective cover sealing the post-tensioning steel at the anchorage.

Inlet: Tubing or duct used for injection of the grout into the duct.

Outlet: Tubing or duct to allow the escape of air, water, grout and bleed water from the duct.

Post-tensioning: A method of prestressing where tensioning of the tendons occurs after the concrete has reached a specified strength.

Prestressing Steel: The steel element of a post-tensioning tendon, which is elongated and anchored to provide the necessary permanent prestressing force.

Post-Tensioning Scheme or Layout: The pattern, size and locations of post-tensioning tendons provided by the Designer on the Contract Plans.

Post-tensioning System: An assembly of specific models of hardware, including but not limited to anchorage assembly, local zone reinforcement, wedge plate, wedges, inlet, outlet, couplers, duct, duct connections and grout cap, used to construct a tendon of a particular size and type. The entire assembly must meet the system pressure testing requirement. Internal and external systems are considered independent of one another.

Pressure Rating: The estimated maximum pressure that water in a duct or in a duct component can exert continuously with a high degree of certainty that failure of the duct or duct component will not occur (commonly referred to as working pressure).

Set (Also Anchor Set or Wedge Set): Set is the total movement of a point on the strand just behind the anchoring wedges during load transfer from the jack to the permanent anchorages. Set movement is the sum of slippage of the wedges with respect to the anchorage head and the elastic deformation of the anchor components. For bars, set is the total movement of a point on the bar just behind the anchor nut at transfer and is the sum of slippage of the bar and the elastic deformation of the anchorage components.

Strand: An assembly of several high strength steel wires wound together. Strands usually have six outer wires helically wound around a single straight wire of a similar diameter.

Tendon: A single or group of prestressing steel elements and their anchorage assemblies imparting prestress forces to a structural member or the ground. Also, included are ducts, grouting attachments, grout and corrosion protection filler materials or coatings.

Tendon Size: The number of individual strands of a certain strand diameter or the diameter of a bar.

Tendon Type: The relative location of the tendon to the concrete shape, internal or external.

Thixotropic: The property of a material that enables it to stiffen in a short time while at rest, but to acquire a lower viscosity when mechanically agitated.

Wedge Plate: The hardware that holds the wedges of a multi-strand tendon and transfers the tendon force to the anchorage assembly. (Commonly referred to as anchor head)

Wedge: A conically shaped device that anchors the strand in the wedge plate.

462-4 Materials.

Meet the requirements of following:

Wire Strand* ....ASTM A 416
Bar**..ASTM A 722
Water...Section 923
Grout ....Section 938
Epoxy Grout..Section 926
Magnesium Ammonium Phosphate Concrete ....Section 930
Elastomeric Coating System ....Section 975

462-4.1 Prestressing Steel:

(a) Strand: Unless otherwise noted on the plans, use uncoated strand meeting requirements of Section 933 (Grade 270, low relaxation 7-wire strand meeting the requirements of ASTM A 416).

(b) Bar: Unless otherwise noted on the plans, uncoated Grade 150, high strength, coarse thread bar meeting the requirements of ASTM A 722, Type II.

462-4.2 Post-Tensioning System: Use approved post-tensioning systems, of the proper size and type to construct tendons shown on the Contract Documents. Substitution of components of approved post-tensioning systems is not permitted. For permanent applications, the use and location of bar couplers is subject to approval by the Engineer. Use only post-tensioning systems that utilize tendons fully encapsulated in anchorages and ducts. Systems which transfer prestress force by bonding the prestress steel strand directly to concrete are not permitted. Embedded anchors for bars are permitted. Systems utilizing formed, ungrouted voids or "Diablos" are not permitted. Strand or tendon couplers are not permitted.

462-4.2.1 Post-Tensioning Anchorages: Ensure that the anchorages develop at least 95% of the actual ultimate tensile strength of the prestressing steel, when tested in an unbonded state, without exceeding the anticipated set.

Design anchorages so that the average concrete bearing stress is in compliance with the "AASHTO LRFD Bridge Design Specifications". Test and provide written certification that anchorages meet or exceed the testing requirements in the AASHTO LRFD Bridge Construction Specifications.

Galvanize the embedded body of the anchorage in accordance with ASTM 123. Other components of the anchorage including wedges, wedge plate and local zone reinforcement are not required to be galvanized. Construct the bearing surface and wedge plate from ferrous metal. Equip all anchorages with a permanent grout cap that is vented and bolted to the anchorage.

Provide wedge plates with centering lugs or shoulders to facilitate alignment with the bearing plate.

Cast anchorages with grout outlets suitable for inspection from either the top or front of the anchorage. The grout outlet will serve a dual function of grout outlet and post-grouting inspection access. The geometry of the grout outlets must facilitate being drilled using a 3/8" diameter straight bit to facilitate endoscope inspection directly behind the anchor plate. 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.

Trumpets associated with anchorages will be made of either ferrous metal or polypropylene plastic material conforming with the requirements stated in 462-4.2.5.5. The thickness of the trumpet at the transition location (choke point) will not be less than the thickness of the duct as established in 462-4.2.5.5. Alternately, the trumpet material may be polyolefin containing antioxidant(s) with a minimum Oxidation Induction Time (OIT) according to ASTM D 3895 of not less than 20 minutes. Perform OIT test on samples taken from the finished product. Test the remolded finished polyolefin material for stress crack resistance using ASTM F 2136 at an applied stress of 348 psi resulting in a minimum failure time of 3 hours.

462-4.2.2 Bar Couplers: Use couplers meeting the requirements of AASHTO LRFD Bridge Design Specifications and Bridge Construction Specifications. Test and provide written certification that the couplers meet or exceed the testing requirements in the AASHTO LRFD Bridge Construction Specifications.

462-4.2.3 Inlets, Outlets, Valves and Plugs: Provide permanent grout inlets, outlets, and threaded plugs made of ASTM A 240 Type 316 stainless steel, nylon or polyolefin materials. For products made from nylon, the cell class of the nylon according to ASTM D5989 shall be S-PA0141 (weather resistant), S-PA0231 or S-PA0401 (ultimate strength not less than 10,000 psi with UV stabilizer added). Products made from polyolefin shall contain antioxidant(s) with a minimum Oxidation Induction Time (OIT) according to ASTM D 3895 of not less than 20 minutes. Perform OIT test on samples taken from the finished product. Test the remolded finished polyolefin material for stress crack resistance using ASTM F 2136 at an applied stress of 348 psi resulting in a minimum failure time of 3 hours. All inlets and outlets will be equipped with pressure rated mechanical shut-off valves or plugs. Inlets, outlets, valves and plugs will be rated for a minimum pressure rating of 150 psi. Use inlets and outlets with a minimum inside diameter of 3/4 inch for strand and 3/8 inch for single bar tendons and four-strand duct.

Provide dual mechanical shutoff valves when performing vertical grouting. Specifically designate temporary items, not part of the permanent structure, on the PT System drawings. Temporary items may be made of any suitable material.

462-4.2.4 Permanent Grout Caps: Use permanent grout caps made from approved polymer or ASTM A 240 Type 316L stainless steel. The approved resins used in the polymer shall be either nylon, Acrylonitrile Butadiene Styrene (ABS) or polyester. For products made from nylon, the cell class of the nylon according to ASTM D5989 shall be S-PA0141 (weather resistant), S-PA0231 or S-PA0401 (ultimate strength not less than 10,000 psi with UV stabilizer added). Seal the cap with "O" ring seals or precision fitted flat gaskets placed against the bearing plate. Place a grout vent on the top of the cap. Grout caps must be rated for a minimum pressure rating of 150 psi. Use ASTM A 240 Type 316L stainless steel bolts to attach the cap to the anchorage. When stainless steel grout caps are supplied, provide certified test reports documenting the chemical analysis of the steel.

462-4.2.5 Duct and Pipe:

462-4.2.5.1 General: Use only plastic duct, steel pipe or a combination of plastic duct and steel pipe. Ensure that all connectors, connections and components of post-tensioning system hardware are air and water tight and pass the pressure test requirements herein. Use smooth plastic duct in all post-tensioning systems used for external tendons. Use corrugated plastic duct in all post-tensioning systems used for all internal tendons except where steel pipe is required.

462-4.2.5.2 Duct or Pipe Minimum Diameter: For prestressing bars, provide duct with a minimum internal diameter of at least 1/2 inch larger than the outside diameter, measured across the deformations. For prestressing bars with couplers, size the duct to be 1/2 inch larger than the diameter of the bar and/or coupler.

For multi-strand tendons, provide ducts with a minimum cross-sectional area 2 1/2 times the cross-sectional area of the prestressing steel.

462-4.2.5.3 Connection Tolerance Between Pipe and Duct: Steel pipe and plastic duct may be connected directly to each other when the outside diameters do not vary more than ± 0.08 inch. Use a reducer when the diameters of the steel pipe and the plastic duct are outside of this tolerance.

462-4.2.5.4 Steel Pipes: Use galvanized schedule 40 steel pipes where shown in the plans and in all deviation blocks and diaphragms.

462-4.2.5.5 Corrugated Plastic Duct: Do not use ducts manufactured from recycled material. Use seamless fabrication methods to manufacture ducts.

Use corrugated duct manufactured from non-colored, unfilled polypropylene meeting the requirements of ASTM D4101 "Standard Specification for Polypropylene Plastic Injection and Extrusion Materials" with a cell classification range of PP0340B14541 to PP0340B67884. The duct shall be white in color containing antioxidant(s) with a minimum Oxidation Induction Time (OIT) according to ASTM D 3895 of 20 minutes and containing a non-yellowing light stabilizer. Perform OIT test on samples from the finished product. Furnish duct with a minimum thickness as defined in the following table:

Duct Shape	Duct Diameter	Duct Thickness
Flat	any size	0.08 inch
Round	0.9 inch	0.08 inch

Duct Shape	Duct Diameter	Duct Thickness
Round	2.375 inches	0.08 inch
Round	3.0 inches	0.10 inch
Round	3.35 inches	0.10 inch
Round	4.0 inches	0.12 inch
Round	4.5 inches	0.14 inch
Round	5.125 inches	0.16 inch
Round	5.71 inches	0.16 inch

462-4.2.5.5.1 Testing Requirements for Corrugated Plastic Duct: Ensure that the duct system components and accessories meet the requirements of Chapter 4, Articles 4.1 through 4.1.8 of International Federation of Structural Concrete (FIB) Technical Report, Bulletin 7, titled “Corrugated Plastic Duct for Internal Bonded Post-Tensioning” as modified herein.

The requirements in FIB Technical Report, Bulletin 7, are modified as follows: Conduct the lateral load resistance test (FIB 4.1.4), without the use of a duct stiffener plate, using a load of 150 lbs. for all sizes; Wear resistance of duct (FIB 4.1.7) must not be less than 0.06 inch for duct up to 3.35 inches in diameter and not less than 0.08 inch for duct greater than 3.35 inches in diameter; Bond length test (FIB 4.1.8) must achieve 40 % GUTS in a maximum length of 16 duct diameters.

462-4.2.5.5.2 Minimum Bending Radius for Corrugated Plastic Duct: In addition to the component testing stated herein, the manufacturer shall establish, through testing, the minimum bending radius for the duct. The test consist of a modified duct wear test as described in Chapter 4, Article 4.1.7 of FIB Technical Report, Bulletin 7, titled “Corrugated Plastic Duct for Internal Bonded Post-Tensioning”. The test apparatus shall be identical to the wear test apparatus with the same clamping force as a function of the number of strands in the duct; however, modify the procedure as follows: do not move the sample along the strand to simulate wear; the test duration will be 7 days. Upon completion of the test duration, remove the duct and the minimum wall thickness along the strand path must not be less than 0.06 inch for duct up to 3.35 inches diameter and not less than 0.08 inch for duct greater than 3.35 inches in diameter.

462-4.2.5.5.3 Corrugated Duct Connections and Fittings: Make all splices, joints, joints between segments (segmental construction), couplings and connections to anchorages with devices or methods (i.e. mechanical couplers, plastic sleeves in conjunction with shrink sleeve) producing a smooth interior alignment with no lips or kinks. Design all connections and fittings to be airtight. Duct tape is not permitted to join or repair duct connections.

Construct connections and fittings from polyolefin materials containing antioxidant stabilizer(s) meeting the requirements established in 462-4.2.3 or 462-4.2.5.5.

For post-tensioned systems intended for use with segmental constructed box girder bridges, the post-tensioning system shall include duct couplers at the segment joints. The tendon duct coupler located at the segment joint shall be mounted perpendicular to the bulkhead and designed to receive a duct at an angle of 6 degrees deviation from perpendicular. The coupler must be able to accommodate angular deviation of the duct without the tendon strands touching the duct or coupler on either side of the segment joint.

462-4.2.5.6 Smooth Duct: Use smooth duct manufactured from 100% virgin polyethylene resin meeting the requirements of ASTM D 3350 with a minimum cell class of 344464C. Use resin containing antioxidant(s). Perform OIT test on samples taken from the finished product resulting in a minimum Oxidative Induction Time (OIT) according to ASTM D 3895 of 40 minutes. Manufacture duct with a dimension ratio (DR) of 17.0 or less as established by either ASTM D 3055 or ASTM F 714 as appropriate for the manufacturing process used.

Use smooth duct meeting the minimum pressure rating (working pressure) of 100 psi and manufactured to either of the following Specifications: ASTM D 3035 “Standard Specifications for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Controlled Outside Diameter” or ASTM F 714 “Standard Specification for Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter”.

462-4.2.5.6.1 External Smooth Duct Connections: Use heat welding techniques to make splices between sections of plastic duct, in accordance with the duct manufacturers instructions or make connections with electrofusion coupler or other mechanical couplers meeting the material requirements of this Specification. Ensure all connections have a minimum pressure rating (working pressure) of 100 psi, produce a smooth interior alignment and a connection with no lips or kinks.

Ensure all connections between steel pipe embedded in concrete and plastic duct are made by using a mechanical coupler or a circular sleeve made of Ethylene Propylene Deine Monomer (EPDM), having a minimum pressure rating (working pressure) of 100 psi. Use EPDM materials having 100 % quality retention as defined by ASTM D 1171 Ozone Chamber Exposure Method B.

Use EPDM sleeves having a minimum wall thickness of 3/8 inch and be reinforced with a minimum of four ply polyester reinforcement. Use a 3/8 inch wide power seated band and clamps constructed from 316 stainless steel on each end of the boot to seal against leakage of grout. Install the band with an 80 to 120 lb seating force.

462-4.2.5.7 Corrugated Ferrous Metal Ducts: Do not use corrugated ferrous metal ducts in any location.

462-4.2.5.8 Shipping and Storage of Ducts: Furnish duct with end caps to seal the duct interior from contamination. Ship in bundles which are capped and covered during shipping and storage. Protect ducts against ultraviolet degradation, crushing, excessive bending, dirt contamination and corrosive elements during transportation, storage and handling. Do not remove end caps supplied with the duct until the duct is incorporated into the bridge component. Store duct in a location that is dry and protected from the sun. Storage must be on a raised platform and completely covered to prevent contamination. If necessary, wash duct before use to remove any contamination.

462-4.2.6 Internal Duct Mechanical Couplers, O-Rings, Segment Seal Assemblies and Heat Shrink Sleeve Requirements: Ducts for prestressing bars used exclusively for temporary post-tensioning are not required to be coupled across segment joints.

462-4.2.6.1 Mechanical Couplers: Construct mechanical internal duct couplers with stainless steel, plastic or a combination of these materials. Use plastic resins meeting the requirements for of sections 462-4.2.3 or 462-4.2.5.5 to construct plastic couplers. Use ASTM A 240 Type 316 stainless steel to make metallic components.

462-4.2.6.2 O-rings: Provide O-ring duct coupling assemblies and **s**egment seal mounting assemblies made from plastic resins meeting the requirements of sections 462-4.2.3 or 462-4.2.5.5.

Furnish standard O-ring material (diameter $\leq$ 0.25 inch) conforming with the following requirements:

Mechanical Properties

Shore hardness, A 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 D471.........................+ 10 %

Environmental Resistance

Ozone Resistance Exposure Method B, ASTM D1171.. Pass
Low Temp. Non-brittle after 3 Min. @ -40°F, ASTM D2137.. Pass

Furnish segment seal assemblies for large diameter compression seals, used to couple ducts at segment joints, which conform with the requirements stated above and with the following additions and changes:

Mechanical Properties

Shore hardness, A ASTM D2240 30-40
Tensile strength, ASTM D412.......................... 600 psi Min.
Compression Set Method B 22 hours @257° F, ASTM D395.. 60 %

Compression Force - The maximum force to compress the O-ring to its final compressed position shall not be greater than 25 psi times the area encircled by the O-ring.

Voided Area - The seal shall be designed to accommodate the material flow within its own cross sectional area by using a hollow or voided design.

Mounting Assemblies - Assemblies holding the O-ring must mount to the form bulkhead and provide for duct alignment.

462-4.2.6.3 Heat Shrink Sleeves: Furnish heat shrink sleeves having unidirectional circumferential recovery manufactured specifically for the size of the duct being coupled consisting of an irradiated and cross linked high density polyethylene backing for external applications and linear-density polyethylene for internal applications. Furnish adhesive having the same bond value to steel and polyolefin plastic materials. Ensure the heat shrink sleeves have an adhesive layer that will withstand 150° F operating temperature and meet the requirements of the following table:

Property	Test Method	Minimum Requirements	
		Internal Application	External Application
Minimum Fully Recovered Thickness		92 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 psi	3,480 psi
Hardness	ASTM D 2240	46 Shore D	52 Shore D
Water Absorption	ASTM D 570	Less than 0.05%	Less than 0.05%
Color		Yellow	Black
Minimum Recovery	Heat Recovery Test	33%	23%

Install heat shrink sleeves using procedures and methods in accordance with the manufacturer’s recommendations.

462-4.2.7 System Test Requirements: For each family of post-tensioning systems, assemble systems and perform the pressure test defined herein. For each family of post-tensioning systems test two assemblies (largest and smallest) from the family. The post-tensioning assembly includes at least one of each component required to make a tendon from grout cap to grout cap. If applicable, include plastic duct to steel pipe connections and segment duct couplers.

462-4.2.7.1 Grouting Component Assembly Pressure Test: Assemble anchorage and grout cap with all required grouting attachments (grout tube, valves, plugs, etc.). Seal the opening in the anchorage where the duct connects. Condition the assembly by maintaining a pressure of 150 psi in the system for 3 hours. After conditioning, the assembly must sustain a 150 psi internal pressure for five minutes with no more than 15 psi reduction in pressure. For systems using the same anchorages, grout caps and grouting attachments as a previously approved system, the Grouting Component Assembly Pressure Test may include documentation from a previous submittal with written certification that the same components are being utilized in both anchorages.

462-4.2.7.2 External Duct Systems: System testing for external duct requires two additional tests. (1) The anchorage and its connection to the duct/pipe assembly must be tested in accordance with and meet the requirements for internal duct systems~~.~~ (duct/pipe assembly consists of all components internal to the diaphragm concrete). Test the assembly at 1.5 psi. (2) The duct and pipe assembly consisting of all external duct connections (welded duct splices, duct-pipe, etc.) and a grout vent must comply with the following test. Condition the assembly by maintaining a pressure of 150 psi in the system for 3 hours. After conditioning, the assembly must sustain a 150 psi internal pressure for five minutes with no more than 15 psi reduction in pressure. The length of the test pipe assembly for the second test is 15 feet.

462-4.2.7.3 Internal Duct Systems: Perform a system test of the assembly for compliance with the requirements of Chapter 4, Article 4.2, Stage 1 and Stage 2 Testing contained in FIB Technical Report, Bulletin 7, titled “Corrugated Plastic Duct for Internal Bonded Post-tensioning”. For bar systems modify the system test length to 15 feet. For systems being tested for use in precast segmental construction, modify this test to include one duct coupler (or O-ring assembly) which is to be used at the segment joint.

Test the coupler for proper function by casting the coupler into a two part concrete test block using match cast techniques. Use blocks that are at least 12 inch x 12 inch x 12 inch. After the concrete has hardened, pull the blocks apart and clean the surface of any bond breaker materials. Using an external apparatus clamp the blocks together and maintain 40 psi pressure on the block cross-section during the pressure test. Do not apply epoxy between the blocks for this portion of the test. Pressurize the duct within the test block to 5 psi and lock-off the outside air source. The assembly must sustain a 5 psi internal pressure for five minutes with no more than a 0.5 psi reduction in pressure. Separate the duct coupler blocks from the duct system remove the clamping device and place a 1/16 inch layer of epoxy on the face of both blocks, clamp the blocks together and maintain a pressure of 40 psi on the block cross-section for 24 hours. Upon removal of the clamping force, demolish the blocks. The coupler and the attached ducts should be intact and free of epoxy, and properly attached without crushing, tearing or other signs of failure.

462-4.3 Grout: Use only grouts that are on the Department’s Qualified Products List (QPL) meeting the requirements of Section 938. Select the post-tensioning grout for use by the proper application either repair, horizontal or vertical. Grout will be mixed with potable water meeting the requirements of Section 923. Maintain grout fluidity in strict compliance with the grout manufacturer’s recommendations and test with a flow cone.

462-4.3.1Grout Storage: Store grout in a location that is both dry and convenient to the work. Storage in the open must be on a raised platform and with adequate waterproof covering to protect the material. On site storage of grout is limited to a maximum period of one month.

462-4.4 Samples for Testing and Identification:

462-4.4.1 General: Testing must conform to the applicable ASTM Specifications for the prestressing material used.

Furnish all material samples for testing at no cost to the Department.

Consider the job site or site referred to herein, as the location where the prestressing steel is to be installed, whether at the bridge site or at the casting yard.

462-4.4.2 Prestressing Steel: Furnish samples for testing as described below for each manufacturer of prestressing strand and bar to be used on the project.

With each sample of prestressing steel strand or bar furnished for testing, submit a certification stating the manufacturer’s minimum guaranteed ultimate tensile strength of the sample furnished.

The Engineer will sample the following materials, at the plant or jobsite, from the prestressing steel used for post-tensioning operations:

(a) For strand: three randomly selected samples, 5 feet long, per manufacturer, per size of strand, per shipment, with a minimum of one sample for every ten reels delivered.

(b) For bars: three randomly selected samples, 5 feet long, per manufacturer, per size of bar, per heat of steel, with a minimum of one sample per shipment.

One of each of the samples furnished to represent a LOT, will be tested. The remaining sample(s), properly identified and tagged, will be stored by the Engineer for future testing. In the event of loss or failure of the component the stored sample will be utilized to evaluate for minimum strength requirements. For acceptance of the LOT represented, test results must show 100% of the guaranteed ultimate tensile strength.

462-4.4.3 LOTs and Identification: A LOT is that parcel of components as described herein. All bars, of each size from each mill heat of steel, and all strand from each manufactured reel to be shipped to the site must be assigned an individual LOT number and must be tagged in such a manner that each such LOT can be accurately identified at the job site. Submit records to the Engineer identifying assigned LOT numbers with the heat, or reel of material represented. All unidentified prestressing steel, or bars received at the site will be rejected. Also, loss of positive identification of these items at any time will be cause for rejection.

Provide a copy of the grout Quality Control Data Sheet to the Engineer, from the manufacturer, for each LOT number and shipment sent to the job site. Materials with a total time from manufacturer, in excess of six months, must be retested and certified by the supplier before use or be removed from the project and replaced.

462-4.5 Approval of Materials: The approval of any material by the Engineer will not preclude subsequent rejection if the material is damaged in transit or later damaged or found to be defective.

462-5 Testing by the Contractor: (Not Required on Post-tensioned, Precast Flat Slab Bridges and Double Tee Bridges).

462-5.1 Tendon Modulus of Elasticity Test: If required in the Contract Documents or ordered by the Engineer, perform a tendon modulus of elasticity test in accordance with the following procedure.

For the purpose of accurately determining the tendon elongations while stressing, bench test two samples of each size of tendon to determine the modulus of elasticity prior to stressing the initial tendon.

For the purpose of this test, the bench length between anchorages must be at least 40 feet and the tendon duct at least 2 inches clear of the tendon all around. The test procedure must consist of stressing the tendon at an anchor assembly with a load cell at the dead end. Tension the test specimen to 80% of ultimate in ten increments and then detention from 80% of ultimate to zero in ten decrements. For each increment and decrement, record the gauge pressure, elongations and load cell force. Note elongations of the tendon for both ends and the central 30 feet, measured to an accuracy of ± 1/32 inch. Correct the elongations for the actual anchorage set of the dead end.

Calculate the modulus as follows:

$E = PL/Adl$

where;

P= force in tendon,

L= distance between pulling wedges and dead end wedges or exact length in center 30 feet of the tendon.

A= cross sectional area of the tendon based on nominal area.

dl= strand elongation for load P.

If the bench test varies from the modulus of elasticity used for the shop or working drawings by more than 1%, submit revisions to the theoretical elongations to the Engineer for approval.

When the observed elongations of the tendons in the erected structure fall outside the acceptable tolerances, or to otherwise settle disputes, additional Tendon Modulus of Elasticity Tests may be required to the satisfaction of the Engineer.

If the source of prestressing steel changes during the project, additional test series or substantiation from previous projects, not to exceed two per source will be required.

The apparatus and methods used to perform the test must be submitted to the Engineer for approval. Tests must be conducted in the Engineer's presence.

462-5.2 In Place Friction Test: For tendons in excess of 100 feet long, test in place a minimum of one tendon in tendon group performing the same function. Functional tendon groups are cantilever tendons, continuity tendons, draped external tendons or continuous profiled tendons passing through one or more spans. The selected tendon will represent the size and length of the group of tendons being tested. The in-place friction test is not required on projects with straight tendons used in flat slabs or precast voided slabs.

The test procedure consists of stressing the tendon at an anchor assembly with a load cell or a second certified jack at the dead end. Stress the test specimen to 80% of ultimate tendon strength in eight equal increments. For each increment, record the gauge pressure, elongations and load cell force. Take into account any wedge seating in both the live end (i.e., back of jack) and the dead end (i.e., back of load cell) and any friction within the anchorages, wedge plates and jack as a result of slight deviations of the strands through these assemblies. For long tendons requiring multiple jack pulls with intermediate temporary anchoring, keep an accurate account of the elongation at the jacking end allowing for intermediate wedge seating and slip of the jack's wedges.

If the elongation's fall outside the ± 5% range compared to the anticipated elongations, investigate the reason and make detailed calculations confirming the final tendon forces are in agreement with the requirements of the approved Plans.

In reconciling theoretical and actual elongations, do not vary the value of the expected friction and wobble coefficients by more than ± 10%. Significant shortfall in elongations is indicative of poor duct alignments and/or obstructions. Correct or compensate for such elongations in a manner proposed by the Contractor and reviewed and approved by the Engineer at no additional cost to the Department.

The Engineer will require one successful friction test for each tendon group for the project.

If there are irreconcilable differences between forces and elongations, or other difficulties during the course of routine stressing operations, the Engineer may require additional in place friction tests.

The apparatus and methods used to perform the test must be submitted to the Engineer for approval. Tests must be conducted in the Engineer's presence.

462-5.3 Tests Reports Required: Submit two test reports of the "Tendon Modulus of Elasticity Test" to the Engineer at least 30 days before installing the tendon.

Submit two test reports of the "In Place Friction Test" to the Engineer within two weeks after successful installation of the tested tendon.

462-5.4 Payment for Testing: Payment for contractor tendon modulus or friction testing shall be included in the price of the post-tensioning.

462-5. 5 Application of Test Results: Reevaluate the theoretical elongations shown on the post-tensioning shop or working drawings using the results of the tests for Tendon Modulus of Elasticity and In Place Friction as appropriate and correct as necessary. Submit revisions to the theoretical elongations to the Engineer for approval.

462-6 Protection of Prestressing Steel.

462-6.1 Shipping, Handling and Storage: Protect all prestressing steel against physical damage and corrosion at all times, from manufacturer to final grouting or encasing in the concrete. The Engineer will reject prestressing steel that has sustained physical damage. Carefully inspect any reel that is found to contain broken wires during use and remove and discard lengths of strand containing broken wires. The wire must be bright and uniformly colored, having no foreign matter or pitting on its surface.

Prestressing steel must be packaged in containers for protection of the steel against physical damage and corrosion during shipping and storage. A corrosion inhibitor, which prevents rust, must be placed in the package, or be incorporated in a corrosion inhibitor carrier type packaging material. The corrosion inhibitor must have no deleterious effect on the steel or the concrete or bond strength of steel to concrete. Inhibitor carrier type packaging material must conform to the provisions of Federal Specification MIL-P-3420. Immediately replace or restore packaging damaged from any cause, to the original condition.

The shipping package must be clearly marked with a statement that the package contains high-strength prestressing steel, the care to be used in handling, and the type, kind and amount of corrosion inhibitor used, including the date when placed, safety orders and instructions for use. Specifically designate low relaxation (stabilized) strands per requirements of ASTM A 416. Strands not so designated will be rejected.

462-6.2 During Installation in the Structure: The time between the first installation of the prestressing steel in the duct and the completion of the stressing and grouting operations shall not exceed seven calendar days. Any light surface corrosion forming during this period of time will not be cause for rejection of the prestressing steel.

Flushing of grout is not permitted and vacuum grouting is required to repair all voids and blockages as defined in 462-11.5.7. Flushing of ducts is only permitted as defined in 462-9 and 462-10.5. When flushing is permitted, use flush water containing slack lime (calcium hydroxide) or quicklime (calcium oxide) in the amount of 0.17 lb/gal.

Except when waived by the Engineer in writing, failure to grout tendons within the seven calendar days specified will result in stoppage of the affected work in accordance with 8-6.

462-7 Fabrication.

462-7.1 General: Accurately and securely fasten all post-tensioning anchorages, ducts, inlet and outlet pipes, miscellaneous hardware, reinforcing bars, and other embedments at the locations shown on the plans or on the approved Shop or Working Drawings or as otherwise approved by the Engineer. Construct tendons using the minimum number of duct splices possible.

462-7.2 Ducts: Accurately align ducts and position at the locations shown on the plans or according to the approved Shop or Working Drawings or as otherwise approved by the Engineer. Securely fasten all internal ducts in position at regular intervals not exceeding 30 inches for steel pipes, 24 inches for round plastic duct and 12 inches for flat ducts to prevent movement, displacement or damage from concrete placement and consolidation operations. Show the method and spacing of duct supports on appropriate Shop Drawings. Ensure that ducts for external tendons are straight between connections to internal ducts at anchorages, diaphragms and deviation saddles and are supported at intermediate locations according to the plans or approved shop drawings.

Ensure that all alignments, including curves and straight portions, are smooth and continuous with no lips, kinks or dents. This also applies to curves in pre-bent steel pipe.

Carefully check and repair all ducts as necessary before placing any concrete.

After installing the ducts and until grouting is complete, ensure that all ends of ducts, connections to anchorages, splices, inlets and outlets are sealed at all times. Provide an absolute seal of anchorage and duct termination locations by using plumber's plugs or equal. Grout inlets and outlets shall be installed with plugs or valves in the closed position. Leave low point outlets open. The use of duct tape is not permitted.

462-7.3 Splices and Joints: All splices, joints, couplings, connections (inlet and outlet) and valves shall be part of the approved post-tensioning system. Approved shrink-sleeve material may be used to repair duct. The use of any tape to repair or seal duct is not permitted.

462-7.4 Location of Grout Inlets and Outlets: Place grout inlets and outlets at locations as shown on the plans and shop drawings. Equip all grout inlets and outlets with positive shut-off devices. At a minimum, grout inlets and outlets shall be placed in the following positions:

(a) Top of the tendon anchorage;

(b) Top of the grout cap;

(c) At the high points of the duct when the vertical distance between the highest and lowest point is more than 20 inches;

(d) At a location 3 feet past high points of the duct on the down stream side opposite the direction of grouting;

(e) At all low points;

(f) At major changes in the cross section of the duct;

(g) At other locations required by the Engineer.

Extend grout tubes a sufficient distance out of the concrete member to allow for proper closing of the valves.

462-7.5 Tolerances: Ensure that post-tensioning ducts in their final position are within the following tolerances:

Table of Duct Position Tolerances		
Tolerances	Vertical position Inches	Lateral position Inches
Horizontal tendons in slabs or in slab regions of larger members:	±1/4 [±6]	± 1/2
Longitudinal draped super-Structure tendons in webs: Tendon over supports or in middle third of span	±1/4	±1/4
Tendon in middle half of web depth	±1/2	±1/4

Table of Duct Position Tolerances		
Tolerances	Vertical position Inches	Lateral position Inches
Longitudinal, generally horizontal, superstructure tendons usually in top or bottom of member:	±1/4	±1/4
Horizontal tendons in substructures and foundations:	± 1/2	± 1/2
Vertical tendons in webs	Longitudinal position ±1	Transverse position ±1/4
Vertical tendons in pier shafts	±1/2	±1/4

In all other cases, ensure that tendons are not out of position by more than ± 1/4 inch in any direction.

Ensure entrance and exit angles of tendon paths at anchorages and/or at faces of concrete are within ± 3 degrees of desired angle measured in any direction and any deviations in the alignment are accomplished with smooth transitions without any kinks.

Angle changes at duct joints must not be greater than ± 3 degrees in any direction and must be accomplished with smooth transitions without any kinks.

Locate anchorages within ± 1/4 inch of desired position laterally and ± 1 inch along the tendon except that minimum cover requirements must be maintained.

Position anchorage confinement reinforcement in the form of spirals, multiple U shaped bars or links, to be properly centered around the duct and to start within 1/2 inch of the back of the main anchor plate.

If conflicts exist between the reinforcement and post-tensioning duct, the position of the post-tensioning duct shall prevail and the reinforcement shall be adjusted locally with the Engineer's approval.

462-7.6 Internal Duct Pressure Test: Pressure test each different type and size of duct assembly at the sight of casting before its first time use on the project. Pressure test all assemblies used in a single component constructed for the first time on the project, and thereafter, in groups of not more than 50 components, the Engineer shall randomly select one component per group, but not less than a total of two per project, for testing. Types of components include all post-tensioned components including but not limited too transversely post-tensioned slabs, longitudinally post-tensioned girders, post-tensioned box girder segments, pier and bent caps, and columns. Longitudinal tendons in box segments are exempt from this testing. Test the assemblies in their final position just prior to concrete placement by sealing them at their anchorage or construction joint termini and then by applying compressed air to determine if the assembly connections are pressure tight. In the presence of the Engineer, pressurize the duct to 1.5 psi and lock-off the outside air source then record the pressure loss for a duration of one minute. If the pressure loss exceeds 0.15 psi, find and repair the leaks in the duct assembly using repair methods approved by the Engineer and retest.

462-8 Placing Concrete.

462-8.1 Precautions: Use methods to place and consolidate concrete which will not displace or damage any of the post-tensioning ducts, anchorage assemblies, splices and connections, reinforcement or other embedments. Fabricate all duct splices to prevent duct kinks during concrete placement. Use mandrels as needed to maintain duct alignment and shape.

462-8.2 Proving of Post-Tensioning Ducts: Upon completion of concrete placement, prove that the post-tensioning ducts are free and clear of any obstructions or damage and are able to accept the intended post-tensioning tendons by passing a torpedo through the ducts. Use a torpedo having the same cross-sectional shape as the duct and that is a 1/4 inch smaller all around than the clear, nominal inside dimensions of the duct. Make no deductions to the torpedo section dimensions for tolerances allowed in the manufacture or fixing of the ducts. For straight ducts, use a torpedo at least 2 feet long. For curved ducts, determine the length so that when both ends touch the outermost wall of the duct, the torpedo is 1/4 inch clear of the innermost wall. If the torpedo will not travel completely through the duct, the Engineer will reject the member, unless a workable repair can be made to clear the duct. The torpedo must pass through the duct easily, by hand, without resorting to excessive effort or mechanical assistance.

462-8.3 Problems and Remedies: The Engineer will reject ducts or any part of the work found to be deficient. Perform no remedial or repair work without the Engineer’s approval.

462-9 Installing Tendons.

For tendons subjected to contamination with chlorides (construction location in an aggressive environment), flush the duct before placing the prestressing strands, with lime treated potable water and test for presence of chlorides and oils. Chlorides in the water must be less than 600 ppm. If chloride levels are in excess of 600 ppm, continue to flush the duct until the chloride level is below 250 ppm. Blow oil-free compressed air through the duct to remove any excess water in the duct.

Push or pull post-tensioning strands through the ducts to make up a tendon using methods which will not snag on any lips or joints in the ducts. Strands which are pushed should be rounded off the end of the strand or fitted with a smooth protective cap. During the installation of the post-tensioning strand into the duct, the strand shall not be intentionally rotated by any mechanical device.

Alternatively, strands may be assembled to form the tendon and pulled through the duct using a special steel wire sock (“Chinese finger”) or other device attached to the end. The ends of the strands may not be electric arc welded together for this purpose. Strands may be brazed together for pulling as long as 1 foot of strand from the brazed end is removed after installation. Round the end of the pre-assembled tendon for smooth passage through the duct. Cut strands using an abrasive saw or equal. Flame cutting is not allowed.

Do not install permanent tendons before the completion of testing as required by these Specifications or Plans. As a sole exception, the tendon to be tested in the “In Place Friction Test” may be installed for the test.

462-10 Post-Tensioning Operations.

462-10.1 General: Do not apply post-tensioning forces until the concrete has attained the specified compressive strength as determined by cylinder tests. Conduct all stressing operations in the presence of the Engineer.

462-10.2 Stressing Tendons: Tension all post-tensioning steel with hydraulic jacks so that the post-tensioning force is not less than that required by the plans or approved shop drawings, or as otherwise approved by the Engineer. Do not utilize monostrand jacks to stress tendons with five or more strands.

462-10.2.1 Maximum Stress at Jacking: The maximum temporary stress (jacking stress) in the post-tensioning steel must not exceed 80% of its specified minimum ultimate tensile strength. Do not overstress tendons to achieve the expected elongation.

462-10.2.2 Initial and Permanent Stresses: The post-tensioning steel must be anchored at initial stresses that will result in the long term retention of permanent stresses or forces of no less than those shown on the plans or the approved shop drawings. Unless otherwise approved by the Engineer, the initial stress after anchor set must not exceed 70% of the specified ultimate tensile strength of the post-tensioning steel.

Permanent stress and permanent force are the stress and force remaining in the post-tensioning steel after all losses, including long term creep and shrinkage of concrete, elastic shortening of concrete, relaxation of steel, losses in the post-tensioning steel from the sequence of stressing, friction and unintentional wobble of the ducts, anchor set, friction in the anchorages and all other losses peculiar to the post-tensioning system.

462-10.2.3 Stressing Sequence: Except as noted on the plans or the approved shop drawings, permanent post-tensioning tendons must be stressed from both ends. The required force may be applied at one end and subsequently at the other end or simultaneously at both ends.

Single end stressing is permitted when the following are satisfied:

(a) Space limitations prohibit double end stressing.

(b) The calculated elongation of the post-tensioning steel at the second end is 1/2 inch or less and wedges are power seated.

(c) Single end stressing applied at alternate ends of paired adjacent post-tensioning tendons is required to produce a symmetrical force distribution in agreement with the plan design.

For construction in stages where some tendons are required to be stressed before others, install and stress in accordance with the plans or approved shop drawings or as otherwise approved by the Engineer.

462-10.3 Stressing Equipment: Only use equipment furnished by the supplier of the post-tensioning system (tendons, hardware, anchorages, etc.).

462-10.3.1 Stressing Jacks and Gauges: Each jack must be equipped with a pressure gauge for determining the jacking pressure. The pressure gauge must have an accurate reading gauge with a dial at least 6 inches in diameter.

462-10.3.2 Calibration of Jacks and Gauges: Calibrate each jack and its gauge(s) as a unit. The calibration must consist of three test cycles with the cylinder extension of the jack in various positions (i.e. 2 inch, 4 inch, 8 inch stroke). At each pressure increment, average the forces from each test cycle to obtain an average force. Perform the calibration with the equipment (jack, pump, hoses, etc.) setup in the same configuration that is intended to be used at the job site. The post-tensioning supplier or an independent laboratory shall perform initial calibration of jacks and gauge(s). Use load cells calibrated within the past 12 months to calibrate stressing equipment. For each jack and gauge unit used on the project, furnish certified calibration charts and curves to the Engineer prior to stressing. Supply documentation denoting the load cell(s) calibration date and tractability to NIST (National Institute of Standards and Technology) along with the jack/gauge calibration.

Provide the Engineer with certified calibration charts and curves prior to the start of the work and every six months thereafter, or as requested by the Engineer. Calibrations subsequent to the initial calibration with a load cell may be accomplished by the use of a master gauge. Supply the master gauge to the Engineer in a protective waterproof container capable of protecting the calibration of the master gauge during shipment to a laboratory. Provide a quick-attach hydraulic manifold to enable quick and easy installation of the master gauge to verify the permanent gauge readings. The master gauge shall be calibrated and provided to the Engineer. The master gauge will remain in the possession of the Engineer for the duration of the project.

Any jack repair, such as replacing seals or changing the length of the hydraulic lines, is cause for recalibration using a load cell.

No extra compensation will be allowed for the initial or subsequent calibrations or for the use and required calibrations of the master gauge.

462-10.4 Elongations and Agreement with Forces: Ensure that the forces being applied to the tendon and the elongation of the post-tensioning tendon can be measured at all times.

Elongations shall be measured to the nearest 1/16 inch.

For the required tendon force, the observed elongation must agree within 7% of the theoretical elongation or the entire operation must be checked and the source of error determined and remedied to the satisfaction of the Engineer before proceeding further. Do not overstress the tendon to achieve the theoretical elongation.

In the event that agreement between the observed and theoretical elongations at the required force falls outside the acceptable tolerances, the Engineer may, at his discretion and without additional compensation to the Contractor, require additional tests for “Tendon Modulus of Elasticity” and/or “In-Place Friction” in accordance with 462-5.1 and 462-5.2.

462-10.5 Friction: The Contract Plans were prepared based on the assumed friction and wobble coefficients and anchor set noted on the plans. Submit calculations and show a typical tendon force diagram, after friction, wobble and anchor set losses, on the shop drawings based upon the expected actual coefficients and values for the post-tensioning system to be used. Show these coefficients and values on the shop drawings.

If, in the opinion of the Engineer, the actual friction significantly varies from the expected friction, revise post-tensioning operations so the final tendon force is in agreement with the plans.

When friction must be reduced, graphite may be used as a lubricant, subject to the approval of the Engineer.

462-10.6 Wire Failures in Post-Tensioning Tendons: Multi-strand post-tensioning tendons, having wires which fail, by breaking or slippage during stressing, may be accepted provided the following conditions are met:

(a) The completed structure must have a final post-tensioning force of at least 98% of the design total post-tensioning force.

(b) For precast or cast-in-place segmental construction and for any similar construction that has members post-tensioned together across a common joint face, at any stage of erection, the post-tensioning force across a mating joint must be at least 98% of the post-tensioning required for that mating joint for that stage of erection.

(c) Any single tendon must have no more than a 5% reduction in cross-sectional area of post-tensioning steel due to wire failure.

Any of the above conditions may be waived with approval of the Engineer, when conditions permit the Contractor to propose acceptable alternative means of restoring the post-tensioning force lost due to wire failure.

462-10.7 Cutting of Post-Tensioning Steel: Cut post-tensioning steel with an abrasive saw or plasma torch within 3/4 to 1 1/2 inches away from the anchoring device. Flame cutting of post-tensioning steel is not allowed.

462-10.8 Record of Stressing Operations: Keep a record of the following post-tensioning operations for each tendon installed:

(a) Project name, Financial Project ID;
(b) Contractor and/or subcontractor;
(c) Tendon location, size and type;
(d) Date tendon was first installed in ducts;
(e) Reel number for strands and heat number for bars;
(f) Tendon cross-sectional area;
(g) Modulus of elasticity;
(h) Date Stressed;
(i) Jack and Gauge numbers per end of tendon;
(j) Required jacking force;
(k) Gauge pressures;
(l) Elongations (theoretical and actual);
(m) Anchor sets (anticipated and actual);
(n) Stressing sequence (i.e. tendons to be stressed before and after;
(o) Stressing mode (one end/ two ends/ simultaneous);
(p) Witnesses to stressing operation (Contractor and inspector);
(q) Date grouted

Record any other relevant information. Provide the Engineer with a complete copy of all stressing and grouting operations.

462-10.9 Duct Pressure Field Test: After stressing and before grouting internal or external tendons, install all grout caps, inlets and outlets and test the tendon with compressed air to determine if duct connections require repair. In the presence of the Engineer, pressurize the tendon to 50 psi and lock-off the outside air source. Record pressure loss for one minute. A pressure loss of 25 psi is acceptable for tendons having a length of equal to or less than 150 feet and a pressure loss of 15 psi is acceptable for tendons longer than 150 feet. If the pressure loss exceeds the allowable, repair leaking connections using methods approved by the Engineer and retest.

462-10.10 Tendon Protection: Within four hours after stressing, install grout caps and seal all other tendon openings. If acceptance of the tendon is delayed, seal all tendon openings and temporally weatherproof the open ends of the anchorage. If tendon contamination occurs, remove and replace the tendon.

462-11 Grouting Operations.

462-11.1 Grouting Operations Plan: Submit a grouting operations plan for approval at least six weeks in advance of any scheduled grouting operations. Written approval of the grouting operations plan by the Engineer is required before any grouting of the permanent structure takes place.

At a minimum, the plan will address and provide procedures for the following items:

(a) Names and proof of training for the grouting crew and the crew supervisor in conformance with this specification;

(b) Type, quantity, and brand of materials used in grouting including all certifications required;

(c) Type of equipment furnished, including capacity in relation to demand and working condition, as well as back-up equipment and spare parts;

(d) General grouting procedure;

(e) Duct pressure test and repair procedures;

(f) Method to be used to control the rate of flow within ducts;

(g) Theoretical grout volume calculations;

(h) Mixing and pumping procedures;

(i) Direction of grouting;

(j) Sequence of use of the inlets and outlet pipes;

(k) Procedures for handling blockages;

(l) Procedures for possible post grouting repair.

Before grouting operations begin, a joint meeting of the Contractor, grouting crew and the Engineer will be conducted. At the meeting the grouting operation plan, required testing, corrective procedures and any other relevant issues will be discussed.

462-11.2 Grout Inlets and Outlets: Ensure the connections from the grout pump hose to inlets are free of dirt and are air- tight. Inspect valves to be sure that they can be opened and closed properly.

462-11.3 Supplies: Before grouting operations start, provide an adequate supply of water and compressed air for clearing and testing the ducts, mixing and pumping the grout. Where water is not supplied through the public water supply system, a water storage tank of sufficient capacity must be provided.

462-11.4 Equipment:

462-11.4.1 General: Provide grouting equipment consisting of measuring devices for water, a high-speed shear colloidal mixer, a storage hopper (holding reservoir) and a pump with all the necessary connecting hoses, valves, and pressure gauge. Provide pumping equipment with sufficient capacity to ensure that the post-tensioning ducts to be grouted can be filled and vented without interruption at the required rate of injection in not more than 30 minutes.

Provide an air compressor and hoses with sufficient output to perform the required functions.

Provide vacuum grouting equipment (volumetric measuring type) and experienced operators within 48 hours notice.

462-11.4.2 Mixer, Storage Hopper: Provide a high speed shear colloidal mixer capable of continuous mechanical mixing producing a homogeneous and stable grout free of lumps and undispersed cement. The colloidal grout machinery will have a charging tank for blending and a holding tank. The blending tank must be equipped with a high shear colloidal mixer. The holding tank must be kept agitated and at least partially full at all times during the pumping operation to prevent air from being drawn into the post-tensioning duct.

Add water during the initial mixing by use of a flow meter or calibrated water reservoir with a measuring accuracy equal to one percent of the total water volume.

462-11.4.3 Grout Pumping Equipment: Provide pumping equipment capable of continuous operation which will include a system for circulating the grout when actual grouting is not in progress.

The equipment will be capable of maintaining pressure on completely grouted ducts and will be fitted with a valve that can be closed off without loss of pressure in the duct.

Grout pumps will be positive displacement type, will provide a continuous flow of grout and will be able to maintain a discharge pressure of at least 145 psi.

Pumps will be constructed to have seals adequate to prevent oil, air or other foreign substances entering the grout and to prevent loss of grout or water. The capacity will be such that an optimal rate of grouting can be achieved.

A pressure gauge having a full scale reading of no more than 300 psi will be placed at the duct inlet. If long hoses (in excess of 100 ft) are used, place two gauges, one at the pump and one at the inlet.

The diameter and rated pressure capacity of the grout hoses must be compatible with the pump output.

462-11.4.4 Vacuum Grouting Equipment: Provide vacuum grouting equipment consisting of the following:

(a) Volumeter for the measurement of void volume.

(b) Vacuum pump with a minimum capacity of 10 cfm (0.283 m^3m) and equipped with flow-meter capable of measuring amount of grout being injected.

(c) Manual colloidal mixers and/or dissolvers (manual high speed shear mixers), for voids less than 5.28 gal. (20 liters) in volume.

(d) Standard colloidal mixers, for voids 5.28 gal. (20 liters) and greater in volume.

462-11.4.5 Stand-by Equipment: During grouting operations, provide a stand-by colloidal grout mixer and pump.

462-11.5 Grouting:

462-11.5.1 General: Perform test to confirm the accuracy of the volume-measuring component of the vacuum grouting equipment each day when in use before performing any grouting operations. Use either water or grout for testing using standard testing devices with volumes of 0.5 gal and 6.5 gal and an accuracy of equal to or less than 4 oz. Perform one test with each device. The results must verify the accuracy of the void volume-measuring component of the vacuum grouting equipment within 1% of the test devise volume and must verify the accuracy of the grout volume component of the vacuum grouting equipment within 5% of the test devise volume. Ensure the Engineer is present when any test are performed.

Grout tendons in accordance with the procedures set forth in the approved grouting operation plan. Grout all empty ducts.

462-11.5.2 Temperature Considerations: Maximum grout temperature must not exceed 90°F at the grout inlet. Use chilled water and/or pre-cooling of the bagged material to maintain mixed grout temperature below the maximum allowed temperature. Grouting operations are prohibited when the ambient temperature is below 40°F or is 40°F and falling. Postpone grouting operations if freezing temperatures are forecasted within the next two days and it is expected the concrete temperature surrounding the duct will fall below 40^0 F.

462-11.5.3 Mixing and Pumping: Mix the grout with a metered amount of water.

The materials will be mixed to produce a homogeneous grout. Continuously agitate the grout until grouting is complete.

462-11.5.4 Grout Production Test: During grouting operations the fluidity of the grout must be strictly maintained within the limits established by the grout manufacturer. A target fluidity rate will be established by the manufacturer's representative, based on ambient weather conditions. Determine grout fluidity by use of either test method found in Section 938. Perform fluidity test for each tendon to be grouted and maintain the correct water to cementitious ratio. Do not use grout which tests outside the allowable flow rates.

Prior to grouting empty ducts condition the grout materials as required to limit the grout temperature at the inlet end of the grout hose to 90°F. Prior to performing repair grouting operations with vacuum grouting, condition the grout materials to limit the grout temperature at the inlet end of the grout hose to 85°F. Check the temperature of the grout at the inlet end of the grout hose hourly.

At the beginning of each day's grouting operation, perform a wick induced bleed test in accordance with Section 938. If zero bleed is not achieved at the end of the required time period, do not begin grouting of any new or additional tendons until the grouting operations have been adjusted and further testing shows the grout meets the specified requirements.

462-11.5.5 Grout Operations: Open all grout outlets before starting the grouting operation. Grout tendons in accordance with the Grouting Operations Plan.

Unless approved otherwise by the Engineer, pump grout at a rate of 16 feet to 50 feet of duct per minute. Conduct normal grouting operations at a pressure range of 10 psi to 50 psi measured at the grout inlet. Do not exceed the maximum pumping pressure of 145 psi at the grout inlet for round ducts and 75 psi for flat ducts in deck slabs.

Use grout pumping methods which will ensure complete filling of the ducts and complete encasement of the steel. Grout must flow from the first and subsequent outlets until any residual water or entrapped air has been removed prior to closing the outlet.

Pump grout through the duct and continuously discharge it at the anchorage and grout cap outlets until all free water and air are discharged and the consistency of the grout is equivalent to that of the grout being pumped into the inlet. Close the anchorage outlet and discharge a minimum of 2 gallons of grout from the grout cap into a clean receptacle. Close the grout cap outlet.

For each tendon, immediately after uncontaminated uniform discharge begins, perform a fluidity test using the flow cone on the grout discharged from the anchorage outlet. The measured grout efflux time will not be less than the efflux time measured at the pump or minimum acceptable efflux time as established in Section 938. Alternately, check the grout fluidity using the Wet Density method contained in Section 938. The measured density must fall within the values established in Section 938. The density at the final outlet must not be less than the grout density at the inlet. If the grout fluidity is not acceptable, discharge additional grout from the anchorage outlet and test the grout fluidity. Continue this cycle until an acceptable grout fluidity is achieved. Discard grout used for testing fluidity. After all outlets have been bled and sealed, elevate the grout pressure to ±75 psi seal the inlet valve and wait two minutes to determine if any leaks exist. If leaks are present, fix the leaks using methods approved by the Engineer. Repeat the above stated process until no leaks are present. If no leaks are present, bleed the pressure to 5 psi and wait a minimum of ten minutes for any entrapped air to flow to the high points. After the minimum ten minutes period has expired, increase the pressure as needed and discharge grout at each high point outlet to eliminate any entrapped air or water. Complete the process by locking a pressure of 30 psi into the tendon.

If the actual grouting pressure exceeds the maximum allowed, the inlet will be closed and the grout will be pumped at the next outlet, which has just been, or is ready to be closed as long as a one-way flow is maintained. Grout will not be pumped into a succeeding outlet from which grout has not yet flowed. If this procedure is used, the outlet/inlet, which is to be used for pumping will be fitted with a positive shut-off and pressure gage.

When complete grouting of the tendon cannot be achieved by the steps stated herein, stop the grouting operation. After waiting 48 hours, fill the tendon with grout in accordance with the procedure outlined in 462-11.5.8.

462-11.5.6 Vertical Grouting: Grouting of cable stays is not covered by this specification. For all vertical tendons, provide a standpipe at the upper end of the tendon to store bleed water and grout, maintain the grout level above the level of the prestressing plate and anchorage. This device will be designed and sized to maintain the level of the grout at an elevation which will assure that bleeding will at no time cause the level of the grout to drop below the highest point of the upper anchorage device. Design the standpipe to allow all bleed water to rise into the standpipe, not into the uppermost part of the tendon and anchorage device.

Discharge grout and check grout fluidity as described in 462-11.5.5. As grouting is completed, the standpipe will be filled with grout to a level which assures that, as settlement of the grout occurs, the level of the grout will not drop below the highest point in the upper anchorage device. If the level of the grout drops below the highest point in the anchorage device, immediately add grout to the standpipe. After the grout has hardened, the standpipe will be removed. In the presence of the Engineer, visually inspect for voids using an endoscope or probe. Fill all voids found in the duct using volumetric measuring vacuum grouting processes.

For vertical tendons in excess of 100 feet or if the grouting pressure exceeds the maximum recommended pumping pressure, then grout will be pumped at increasingly higher outlets which have been or are ready to be closed as long as a one-way flow of grout is maintained. Grout will be allowed to flow from each outlet until all air and water have been purged prior to using that outlet for pumping.

462-11.5.7 Construction Traffic and Operations Causing Vibrations: During grouting and for a period of 4 hours upon completion of grouting, eliminate vibrations from all sources such as moving vehicles, jackhammers, compressors, generators, pile driving operations, soil compaction, etc., that are operating within 300 feet down-station and 300 feet up-station of the ends of the span in which grouting is taking place.

462-11.5.8 Post-Grouting Operations and Inspection: Do not remove or open inlets and outlets until the grout has cured for 24 to 48 hours. Remove all outlets located at anchorages and high points along the tendon to facilitate inspection and perform inspections within one hour after the removal of the inlet/outlet. Drill and inspect all high points along the tendon as well as the inlets or outlets located at the anchorages. Depending on the geometry of the grout inlets, drilling may be required to penetrate to the inner surface of the trumpet or duct. Use drilling equipment that will automatically shut-off when steel is encountered. Unless grout caps are determined to have voids by sounding, do not drill into the cap. Perform inspections in the presence of the Engineer using endoscopes or probes. Within four hours of completion of the inspections, fill all duct and anchorage voids using the volumetric measuring vacuum grouting process.

Seal and repair all anchorage and inlet/outlet voids that are produced by drilling for inspection purposes as specified in 462-12.2. Remove the inlet/outlet to a minimum depth of 2 inches. Use an injection tube to extend to the bottom of the drilled holes for backfilling with epoxy.

Post grouting inspection of tendons having a length of less than 150 feet may utilize the following statistical frequency for inspection:

1. For the first 20 tendons, inspect all outlets located at anchors and tendon high points by drilling and probing with an endoscope or probe. If one or more of the inspection locations are found to contain a defect (void), continue testing all tendons until 20 consecutive tendons have been inspected and no voids have been found.

2. When no defects are detected as defined in No. 1 above, the frequency of inspection can be reduced to inspect every other tendon (50%). If a defect is located, inspect the last five tendons grouted. Return to step 1 above and renew the cycle of 100% tendon inspection.

If tendon grouting operations were prematurely terminated prior to completely filling the tendon, drill into the duct and explore the voided areas with an endoscope. Probing is not allowed. Determine the location and extent of all voided areas. Install grout inlets as needed and fill the voids using volumetric measuring vacuum grouting equipment.

462-11.5.9 Grouting Report: Provide a grouting report signed by the Contractor and/or the Subcontractor within 72 hours of each grouting operation for review by the Engineer.

Report the theoretical quantity of grout anticipated as compared to the actual quantity of grout used to fill the duct. Notify the Engineer immediately of shortages or overages.

Information to be noted in the records must include but not necessarily be limited to the following: identification of the tendon; date grouted; number of days from tendon installation to grouting; type of grout; injection end and applied grouting pressure, ratio of actual to theoretical grout quantity; summary of any problems encountered and corrective action taken.

462-12 Forming and Repairs of Holes and Block-Outs.

462-12.1 Repair of Lifting and Access Holes: Repair all holes with Magnesium Ammonium Phosphate Concrete meeting the requirements of Section 930. Immediately before casting the concrete (within 24 hrs.), mechanically clean and roughen the mating concrete surfaces to remove any laitance and expose the small aggregate. Grit blasting or water blasting using a minimum 10,000 psi nozzle pressure is required. Flush surface with water and blow dry. Form, mix, place and cure the material in strict compliance with the manufacture’s recommendations.

Upon completion of the deck grooving, coat the repaired holes, block-outs and an area extending 6 inches outside the perimeter of the repair with Methyl Methacrylate. Apply and remove any excess material as per manufacturer’s instructions.

Alternately, a Type Q Epoxy grout meeting the requirements of Section 926 may be used for the repair material.

462-12.2 Repair of Grout Inlets and Outlets: Place threaded plastic caps in all inlet/outlet locations required in the plans. Repair inlets/outlets as shown on the plans using an epoxy grout, Type E epoxy or Type F-1 epoxy meeting the requirements of Section 926. Prepare the surface to receive the epoxy material in strict compliance with the manufacture’s recommendations.

462-13 Protection of Post-Tensioning Anchorages.

Within seven days upon completion of the grouting, protect the anchorage of post-tensioning bars and tendons as indicated in the plans. The application of the elastomeric coating may be delayed up to 90 days after grouting. Use plastic or stainless steel threaded caps to plug all grout inlets/outlets. Use an epoxy grout, Type Q, meeting the requirements of Section 926 to construct all pour-backs located at anchorages.

Remove all laitance, grease, curing compounds, surface treatments, coatings and oils by grit blasting or water blasting using a minimum 10,000 psi nozzle pressure. Flush surface with water and blow dry. Surfaces must be clean, sound and without any standing water. In case of dispute, use ACI 503 for substrate testing and develop a minimum of 175 psi. tension (pull-off value).

Mix and apply epoxy as per manufacturer's current standard technical guidelines. Construct all pour-backs in leak proof forms creating neat lines. The epoxy grout may require pumping for proper installation. Construct forms to maintain a liquid head to insure intimate contact with the concrete surface. Use vents as needed to provide for the escape of air to insure complete filling of the forms.

Coat the exposed surfaces of all pour-backs and grout caps with an elastomeric coating system meeting the requirements of Section 975 and having a thickness of 30 to 45 mils. Assure concrete, grout caps or other substrates are structurally sound, clean and dry. Concrete must be a minimum of 28 days old. Remove all laitance, grease, curing compounds, surface treatments, coatings and oils by grit blasting or water blasting using a minimum 10,000 psi nozzle pressure to establish the anchor pattern. Blow the surface with compressed air to remove the dust or water. For elastomeric coated pour-backs which are to receive a Class V coating, apply a manufacture's approved primer over the elastomeric coating before applying the Class V coating.

Construct a 2 x 4 ft concrete test block with a similar surface texture to the surfaces to be coated and coat a vertical face with the elastomeric coating system chosen. Determine the number of coats required to achieve a coating thickness between 30 to 45 mils without runs and drips. Mix and apply elastomeric coating as per manufacturer's current standard technical specifications. Spray or roller application is permitted (spray application preferred). Have the coating manufacturer representative on site to supervise and comment on the application of the elastomeric coating onto the test block. Apply coatings using approved and experienced personnel with a minimum of three years experience applying similar polyurethane systems. Submit the credentials of these persons to the Engineer for review and consideration for approval.

462-14 Method of Measurement.

The quantity of post-tensioning tendons to be paid for under this Section will be the computed weight, in pounds, of permanent post-tensioning steel tendons entered into the completed structure and accepted. Measurement will be the theoretical plan length measured from anchorage to anchorage (measured from front face of the bearing plate) with no allowance made for waste or extension past the bearing faces. No measurement will be made for temporary post-tensioning which will be considered incidental to the item "Post-Tensioning Tendons".

For quantity determination, the following unit weights will be used:

Prestressing System	Weight per Unit Length lb/ft
1/2 inch diameter 7 wire strand	0.52
0.6 inch diameter 7 wire strand	0.74
1 inch high strength deformed bar	3.01

1 1/4 inch high strength deformed bar	4.39
1 3/8 inch high strength deformed bar	5.56
1 3/4 inch high strength deformed bar	9.23

462-15 Basis of Payment.

462-15.1 General: Post-tensioning tendons will be paid for at the Contract unit price per pound of steel tendon, completed and accepted. Payment will be full compensation for furnishing, installing, stressing and grouting all temporary and permanent post-tensioning tendons. Payment also includes anchorage assemblies and associated supplemental reinforcing steel required by the supplier, post-tensioning system hardware which is not embedded in concrete, ducts, grout and grouting, all testing, protection of post-tensioning anchorages, vents, inlets, outlets and all labor, materials, tools, equipment and incidentals necessary for completing the work in accordance with the Contract Documents. This payment also includes lubricants in the tendon ducts for friction control and flushing lubricants or contaminants from the ducts. Anchorage components, ducts and similar items of post-tensioning system hardware embedded within precast components or cast-in-place concrete will be deemed to be included in the cost of the precast components or cast-in-place concrete.

If the Contractor constructs the structure with an accepted alternate not detailed on the plans, payment will be based on the unit price bid extended by either the quantities shown in the Contract Documents or the actual quantities used and accepted, whichever is less.

Permanent post-tensioning strand or bar tendons which are an integral part of individual precast concrete segments or units will be measured and paid for under this item and will not be considered incidental to the cost of those precast concrete segments or units.

Payment for post-tensioning will be made following successful placement, stressing, grouting, inspection, protection and approval by the Engineer. Full payment for post-tensioning tendons, within precast segmental concrete structure units, may occur prior to erection of the segments into final position when ducts have been grouted and anchorage protection system applied and the segmental unit otherwise approved for placement by the Engineer.

462-15.2 Payment Items:

Payment will be made under:

Item No. 462- 2- Post-tensioning Tendons - per pound.