ITEM 557.97010003 – EXTERNAL POST-TENSIONING

DESCRIPTION
The work specified in this section shall consist of furnishing, installing, stressing and grouting external post-tensioning tendons in accordance with the details shown on the Contract Drawings and as directed by the Engineer.

References
The following is a listing of the publications referenced in this Section:

American Society for Testing of Materials (ASTM)
ASTM A416 Standard Specification for Steel Strand, Uncoated Seven Wire Strand for Prestressed Concrete
ASTM A77 Standard Specification for Uncoated High Strength Steel Bar for Prestressing Concrete

American Association of State Highway Officials (AASHTO)

Post-Tensioning Institute (PTI)
PTI M50.3-12 Guide Specification for Grouted Post Tensioning
PTI M55.1.12 Specification for Grouting of Post-Tensioned Structures

MATERIALS
The materials to be incorporated into work covered by this Section shall conform to the requirements of the NYSDOT Prestressed Concrete Construction Manual (PCCM) section 4.6 and as set out herein.

1.01 GENERAL
A. Use of a post-tensioning system is subject to the approval of the Engineer. Only post-tensioning systems of the proper type and size for the tendons shown on the plans shall be used. Substitution of components from different post-tensioning systems shall not be allowed. Post-tensioning systems shall utilize tendons fully encapsulated in anchorages and ducts.
B. All post-tensioning material shall be stored in a weatherproof building, shed or container until the time of use, to protect against damage and corrosion.
C. All tendons shall be continuous. No coupling or splicing of tendons will be permitted.

1.02 PRESTRESSING STEEL
A. Strand: Unless otherwise noted on plans, strand shall be uncoated, Grade 270, (1860 MPa) low relaxation 7-wire strand conforming to requirements of ASTM A-416 “Standard Specification for Steel Strand, Uncoated Seven Wire Strand for Prestressed Concrete”.

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B. Thread-Bar: Unless otherwise noted on the plans, prestress bars shall be uncoated, Grade 150 (1035 MPa), high strength deformed thread bars, Type II, conforming to the requirements of ASTM A-722, “Standard Specification for Uncoated High Strength Steel Bar for Prestressing Concrete”.

1.03 PRESTRESS ANCHORAGES

A. All prestressing steel shall be secured at the ends by means of permanent type anchoring devices. Anchors manufactured from composite materials will not be allowed. Prestress anchorages shall develop at least 95 percent of the minimum specified ultimate tensile strength of the prestressing steel. Wedges shall be three-part (Two part wedges shall not be used).

B. Anchorages shall be tested to meet or exceed the testing requirements of the AASHTO LRFD Bridge Construction Specification. Written certification shall be provided to the Engineer.

C. The anchorage system shall be so arranged that the prestressing force in the tendon may be verified prior to the removal of the stressing equipment.

D. For tendon anchorages, the design and furnishing of any reinforcement (in addition to the reinforcement shown on the plans), which is needed to resist bursting and splitting stresses imposed on the concrete by the proposed anchorage system, shall be the responsibility of the Contractor at his expense.

E. Prestress anchorage devices shall effectively distribute prestressing loads to the concrete and shall conform to the following requirements.
   1. Anchorages shall be designed so that the average concrete bearing stress is in compliance with the AASHTO LRFD Bridge Design Specifications.
   2. Bending stresses in the plates or assemblies induced by the pull of the prestressing steel shall not exceed the yield point of the material in the anchorage plate when 95 percent of the ultimate strength of the tendon is applied.

F. The body of the anchorage shall be galvanized in accordance with ASTM 123. Other components of the anchorage including wedges, wedge plate and local zone reinforcement are not required to be galvanized. The bearing surface and wedge plate shall be made from ferrous metal.

G. Wedge plates shall have centering lugs or shoulders to facilitate alignment with the bearing plate. Anchorages shall have a grout vent suitable for inspection from either the top or front of the anchorage. The vent shall facilitate the dual purpose of grouting or post-grouting inspection by drilling, if necessary, using a straight bit, and by insertion of a probe or endoscope.
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1.04 PERMANENT GROUT CAPS
   A. Anchorages shall be fitted with a permanent grout cap made from fiber reinforced plastic, or 316L stainless steel. The resins used in the fiber reinforced plastic shall be either nylon Acrylonitrile-Butadiene-Styrene or polyester. The cap shall have an “O” ring or precision fitted flat gasket seal against the bearing plate. The grout cap shall have a grout vent oriented to the top of the cap. Grout caps shall be rated for a minimum pressure of 150 psi [1 MPa]. Stainless steel (316L) bolts shall be used to attach the grout cap to the anchorage. Certified test reports of the chemical analysis of stainless steel caps is required for verification.

1.05 GROUT VENTS (INLETS AND OUTLETS), VALVES AND PLUGS
   A. In the final detailed configuration (after grouting and inspection), grout vent-pipes at inlets and outlets shall be fitted with a threaded plug or cap to seal the vent.
   B. All inlets and outlets shall be equipped with pressure rated mechanical shut-off valves or plugs. Grout vents at inlets and outlets, valves, vent plugs or caps shall be rated for a minimum pressure rating of 150 psi [1 MPa]. Grout vents (inlets and outlets) shall have a minimum inside diameter of 3/4 inch (20 mm) for strand and 3/8 inch (10 mm) for single bar tendons.
   C. All permanent attachments to anchorages and ducts for grout vents (inlets and outlets) and threaded vent plugs or caps shall be made of 316 stainless steel, nylon or polyolefin materials. For products made from nylon, a cell class of S-PA0141 (weather resistant) is required. 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. The finished polyolefin material shall be tested to satisfy stress crack resistance using ASTM F 2136 at an applied stress of 800 psi [5.5 MPa] with a minimum failure time of 200 hours.
   D. Temporary items, not part of the permanent structure, may be made of any suitable material.
   E. Grout vents (inlets and outlets) shall be provided at locations designated on the Shop Drawings, in accordance with the requirements in this Specification for Construction and installation (below).

1.06 DUCTS
   A. General
      1. Tendon ducts shall meet the requirements of contract drawings and as set out herein.
      2. Smooth plastic duct shall comply with NYSDOT Prestressed Concrete Construction Manual Section 4.6.2.2 for external post-tensioning systems. All duct material shall be sufficiently rigid to withstand loads imposed during internal pressure during grouting while maintaining its shape, remaining in proper alignment and remaining watertight.
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3. The duct system, including splices and joints shall effectively prevent leakage of cement paste or water out of the system and shall effectively contain pressurized grout during grouting of the tendon. The duct system shall also be capable of withstanding water pressure during flushing of a duct in the event the grouting operation is aborted.

B. Connections - Splices between sections of plastic duct shall be made by heat welding techniques in accordance with the duct manufacturer’s instructions, or by mechanical couplers meeting the requirements of this Specification. All connections shall have a minimum pressure rating (working pressure) of 100 psi [0.69MPa]. Connections shall have a smooth interior alignment with no lips or kinks.

C. Shipping and Storage of Ducts - Duct shall be furnished with end caps to seal the duct interior from contamination. Ducts shall be shipped in bundles which are capped and covered during shipping and storage. Ducts shall be protected against ultraviolet degradation, crushing, excessive bending, dirt contamination and corrosive elements during transportation, storage and handling. End caps supplied with the duct shall not be removed until the duct is incorporated into the bridge component. Duct shall be stored 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, duct shall be washed before use to remove any contamination.

D. Mechanical Couplers and Shrink Sleeve Requirements
   1. Mechanical couplers shall be made from stainless steel, plastic or a combination of these materials. Plastic resins for couplers shall meet the requirements for plastic ducts. Grade 316 stainless-steel shall be used for metallic components.
   2. Shrink sleeves shall be manufactured specifically for the size of the duct being coupled consisting of an irradiated and cross linked high density polyethylene backing with an adhesive layer that will withstand 150° F [66° C] operating temperature, meeting the requirements of 4.3.7 of the PTI M50.3-12 Guide Specification for Grouted Post-Tensioning.

1.07 GROUT MATERIALS

A. General:
   Grout used to fill voids in tendons shall consist of a commercially available, pre-packaged, cement-based grout mixture meeting the requirements of §701-10 DUCT GROUTING MATERIAL (STRUCTURES) and this Specification. Pre-packaged grout mix shall be stored, mixed, and pressure injected in accordance with PTI M50.3-12, PTI M55-1.12, and manufacturer’s written recommendations.

B. Grout Testing and Approval:
   The manufacturer shall submit the grout for evaluation and approval by the NYSDOT Materials Bureau in accordance with Test Method 701-18 P, C. Prior to construction, the Contractor shall furnish the Engineer with results of tests,
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performed by a CCRL-approved laboratory, demonstrating that the grout production material meets the requirement of this Specification.

C. Required Properties:
Grout shall have the properties required by Table 701-10 of §701-10. Water for mixing shall be potable, clean and free of injurious quantities or substances known to be harmful to cement or steel. Water shall have chloride, sulfide, sulfate, and nitrate contents no greater than 500, 100, 650 and 13 parts per million, respectively.

CONSTRUCTION DETAILS
2.01 QUALIFICATIONS
A. All grouting operations shall be carried out by workers trained for and experienced in the tasks required. Grouting shall be performed under the immediate control of a person skilled in various aspects of grouting. The person shall provide close observation and control of all grouting operations, as necessary for full compliance with specified requirements. This person shall be named and shall furnish proof of experience as required by the Engineer. At least one individual who is certified as either an ASBI Grouting Technician or a PTI Level 2 Bonded PT Field Specialist shall be present during all grouting operations.

2.02 SUBMITTALS
A. Shop Drawings - Shop drawings are required for the integration of the post-tensioning system, reinforcement and other embedded items, including those for the Contractor’s means and methods of construction for external tendons. The Contractor shall submit detailed shop drawings that address the requirements of Plans and Specifications, and applicable portions of Section 2.5 of NYSDOT PCCM.
   1. Calculations for post-tensioning shall be signed and sealed by a Professional Engineer registered in the State of New York.
B. Grouting Plan - At least six weeks before grouting commences and in accordance with NYSDOT PCCM 8.6, the Contractor shall submit to the Engineer for review and approval a "Grouting Plan". Written approval of the plan is required before grouting proceeds. Any adjustments to the plan as a result of testing to be incorporated. Grouting operations shall be under the supervision of a qualified and experienced person, acceptable to the Engineer. At a minimum the Grouting Operation Plan shall address the following:
   2. Names and proof of training for the grouting crew and the crew supervisor in conformance with this specification;
   3. Type, quantity, and brand of materials used in grouting including all certifications required;
   4. Type of equipment furnished, including capacity in relation to demand and working condition, as well as back-up equipment and spare parts;
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5. General grouting procedure;
6. Duct pressure test and repair procedures;
7. Method to be used to control the rate of flow within ducts;
8. Theoretical grout volume calculations;
9. Mixing and pumping procedures;
10. Direction of grouting;
11. Sequence of use of the inlets and outlet pipes;
12. Procedures for handling blockages;
14. Contractor's QC forms that are to be signed daily by Grout Supervisor

2.03 SAMPLING AND TESTING OF PRESTRESSING ELEMENTS
A. Testing of prestressing elements shall be performed in accordance with ASTM requirements for determining properties and characteristics of ASTM A722 bar tendon and ASTM A416 Prestressing Strands.
B. The following samples of materials, devices and test certifications as designated by the Engineer shall be furnished by the Contractor at his expense for testing. Samples shall be furnished at least 90 days in advance of the time they are to be incorporated into the work. The Engineer reserves the right to reject any material or device which is determined to be defective or was damaged subsequent to testing.
1. Three randomly selected samples, each 5 ft. [1.5 m] long, of post-tensioning bar, per manufacturer, per size of bar, per heat of steel, with a minimum of one sample per shipment.
2. Three randomly selected samples, each 5 ft. [1.5 m] long, of prestressing strand for each size of strand from each shipment, with a minimum number of one sample for every ten reels delivered.
3. One unit of each prestress anchorage to be used on the project
4. For each type of duct material intended for the project, one sample, 4 ft. [1.25 m] feet long, from each production lot.

2.04 LOTS AND IDENTIFICATION (CONTRACTOR'S QUALITY CONTROL)
A. A “Lot” is that parcel of components as described herein. The manufacturer of prestressing steel and prestress anchorages shall assign an individual number to each Lot of strand, wire, bar or devices at the time of manufacture. All bars of each size and mill heat of steel and all strands from each manufactured reel, bundle or package shipped to the project shall be identified by tag or other acceptable means as to Manufacturer's Lot number. The Contractor shall be responsible for establishing and maintaining a procedure by which all prestressing materials and devices can be continuously identified with the manufacturer's Lot number. Items which at any time cannot be positively identified as to Lot number shall not be incorporated into the work.
B. Low relaxation strand shall be clearly identified as required by ASTM A-416. Any strand not so identified will be rejected.
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C. The Contractor shall furnish manufacturer's certified reports covering the tests required by this Specification. A certified test report stating the guaranteed minimum ultimate tensile, yield strength, elongation and composition shall be furnished for each lot of prestressing steel. When requested, typical stress-strain curves for prestressing steel shall be furnished. A certified test report stating strength when tested using the type prestressing steel to be used in the work shall be furnished for each Lot of prestress anchorage devices.

2.05 PROTECTION OF PRESTRESSING STEEL
Tendons in ducts and all prestressing steel shall be protected against all physical damage and corrosion in accordance with NYSDOT PCCM 8.5.2 and as noted herein.

A. After Installation of Tendons in Ducts
1. After installation in ducts, prestressing steel shall be protected from corrosion and the duct system shall be sealed to prevent moisture intrusion from the time of tendon installation to the time of grouting. In addition, all grout vents shall be closed or plugged at all times during the period prior to grouting except that low-point drainage vents shall remain open and point downward.
2. Grouting shall proceed as soon as possible after installation and stressing of the tendons. The time from installing the tendons in an unstressed condition to grouting after stressing shall not exceed the following without approval of the Engineer:
   a. Very damp atmosphere (Relative Humidity (RH) > 70%) or over salt water - 7 days
   b. Moderate to dry atmosphere (RH < 70%) - 10 days
3. Any light surface discoloration or corrosion formed during this period shall not be cause for rejection of the prestressing steel. Pitting shall not be permitted.

B. Tendon Protection between Installation and Stressing – Measures shall be taken to protect the prestressing steel when there is a period of more than 24 hours between installation of the tendons in ducts and stressing. Bare strand projecting out of an anchorage shall be wrapped in continuous plastic sheeting and sealed using waterproof tape extending from the tendon anchorage, and the anchorage opening shall be sealed with plastic and waterproof tape in a sufficient manner to prevent moisture intrusion. All grout vents shall be closed or plugged, all duct connections shall be sealed and drainage vents shall be open, pointing downward.

C. Tendon Protection between Stressing and Grouting
1. Anchorages shall be capped or otherwise sealed again immediately following stressing and cutting of strand tails. The time period between stressing and installation of the permanent end caps shall not exceed 12 hours without approval of the Engineer.
2. In all cases, tendons and ducts shall be thoroughly blown dry with oil-free compressed air immediately prior to sealing or capping of the anchorages. In addition, all grout vents shall remain plugged, sealed or otherwise capped, drainage vents shall be open pointing downward, and all duct connections shall be sealed.

D. Use of Temporary Corrosion Inhibitors - The use of additional corrosion inhibitors such as vapor phase inhibitors or water-soluble oils for temporary corrosion protection after installing the tendons to allow longer time to grouting is not permitted.

2.06 INSTALLATION OF DUCTS, GROUT INJECTION PORTS AND OUTLET VENTS

A. General - All post-tensioning anchorages, ducts, inlet and outlet pipes, shall be accurately and securely fastened at locations shown on the plans or on the approved Shop Drawings or as otherwise approved by the Engineer. Ducts for tendons shall be made using the minimum number of duct splices possible.

B. Ducts

1. Ducts shall be accurately aligned and located as shown on the plans or according to the approved Shop Drawings and as required herein.

2. Ducts shall be straight between connections to pipes at anchorages and deviation saddles and shall be supported at intermediate locations, as required, according to the plans or approved shop drawings. All duct alignments shall be smooth and continuous with no lips, kinks or dents. All splices, joints, couplings, vent connections (inlets and outlets) and valves shall be part of the approved post-tensioning system. Approved shrink-sleeve material may be used to repair duct. The use of duct tape to repair or seal duct shall not be permitted.

C. Grout Vents and Drains

1. Grout pipes shall be installed on each duct to serve as injection or evacuation vents during grouting and to allow the escape of air, water, grout, and bleed water. Drainage vents, pointing downward, shall be provided at low points of tendon profile to allow any accumulated moisture to be drained prior to installing tendons.

2. Inlets and Outlets shall be placed at locations shown on the Contract Plans, on the Approved Shop Drawings, and/or the approved Grouting Operation Plan.

D. Care and Protection of Ducts, Vents, Anchorages and Block Outs - Care shall be taken to ensure that all ducts, anchorages, block outs, openings and vents are kept clean and free of debris, fuel, oils, other contaminants and site trash at all times prior to and after installing the tendons. Temporary plugs, seals and covers shall be used. Minor damage to ducts may be repaired by removing the local damage and splicing duct or couplers onto the intact section (prior to the placing of concrete). Repair of major duct damage requires the removal and replacement of the entire duct section. Connections from grout hose to inlet and ejection ports and to vents shall be kept free from dirt and airtight.

2.07 INSTALLING TENDONS

A. Strands and bars may be pushed or pulled through the ducts to make up a tendon using methods which will not snag on any lips or joints in the ducts.
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B. Multi-strand bundles may be assembled to form the tendon and pulled through the duct using a special steel wire sock (“Chinese finger trap”) or other device attached to the end. The end of the pre-assembled tendon shall be rounded for smooth passage through the duct.

C. All strands and bars shall be cut using an abrasive saw. Flame cutting shall not be allowed.

2.08 POST-TENSIONING OPERATIONS

A. General - Post tensioning of tendons shall be performed in compliance with NYSDOT PCCM 8.5.3, and as noted herein.

B. Assumptions and Forces - Tendons shall be loaded to post tensioning forces shown on the approved shop drawings.

C. Stressing Tendons -
   1. All post-tensioning steel shall be tensioned with hydraulic jacks so that the post-tensioning force is not less than that required by the plans or approved shop drawings, or as approved by the Engineer.
   2. The tensioning process shall be so conducted that tension being applied and the elongation of the post-tensioning steel may be measured at all times. A permanent record shall be kept of gauge pressures and elongations at all times and shall be submitted to the Engineer. The post-tensioning force may be verified as deemed necessary by the Engineer.
   3. For all tendons, excluding post-tensioning bars with lengths less than 20 ft. [6 m], the tendon force measured by gauge pressure shall agree within seven percent of the theoretical elongation or the entire operation shall be checked and the source of error determined and remedied to the satisfaction of the Engineer before proceeding with the work. Elongations shall be measured to the nearest 1/16 inch [1.6 mm]. In determining why the measured tendon force and the theoretical elongation do not agree, the Contractor may elect to establish that the apparent modulus of elasticity of the post-tensioning steel varies from the value shown in the general notes to the plans by conducting a bench test on a full size tendon in accordance with a procedure approved by the Engineer. This test may be performed at a site remote from the project and shall be witnessed by a representative sent by the Engineer.

D. Stressing Sequence - Post tensioning tendons shall be stressed in accordance with the plans and approved shop drawings. The required force may be applied at one end and subsequently at the other end or simultaneously at both ends.

E. Stressing Jacks
   1. Each jack shall be equipped with a pressure gauge having an accurate reading dial at least 6 inches [150 mm] in diameter for determining the jack pressure.
   2. Calibration - Prior to use for stressing on the project, each jack and its gauge shall be calibrated as a unit. Initial jack calibration shall be done, using a proven load cell, by the post-tensioning supplier or by an independent testing laboratory, approved by the Engineer. The calibration shall consist of three test cycles with the cylinder extension of the jack in various positions (i.e. 2”, 4”, 8” stroke). At each pressure increment, the
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forces from each test cycle shall be averaged to obtain an average force. Calibration shall be done with the cylinder extension approximately in the position that it will be when applying the final jacking force and with the jacking assembly in an identical configuration to that which will be used at the job site (i.e. same length hydraulic lines). Load cells used for calibration shall have been calibrated within the last 12 months. Certified calibration calculations and a calibration chart, in English units of measure, shall be furnished to the Engineer for each jack and gauge unit.

F. Wire Failures in Post-Tensioning Tendons - Multi-strand post-tensioning tendons having wires that have failed by breaking or slippage during stressing may be accepted providing that:

1. The completed structure must have a final post-tensioning force of at least 98% of the design total post-tensioning force at the affected sections.
2. Any single tendon must have no more than 5% reduction in cross-sectional area of the post-tensioned steel.
3. If these conditions cannot be met, then the affected tendon(s) shall be removed and replaced.

G. Cutting of Post-Tensioning Steel: Post-tensioning steel shall be cut by an abrasive saw within 3/4 to 1-1/2 inches [19 mm to 38 mm] away from the anchoring device. Flame cutting of prestressing steel is not allowed.

H. Record of Stressing Operations –

1. The Contractor shall keep a record of post-tensioning operations for each tendon installed, in accordance with NYSDOT PCCM 8.5.3.6.1.
2. Any relevant information shall be recorded using forms in Appendix B of PCCM. A complete copy of all stressing and grouting operations shall be provided to the Engineer.

I. Duct Pressure Field Test - After stressing and before grouting internal or external tendons, all grout caps, inlets and outlets shall be installed and the tendon tested with compressed air to determine if duct connections require repair. After pressurizing the tendon to 100 psi [690 kPa] and locking-off the outside air source, a pressure loss of 10 psi [69 kPa] in five minutes will be acceptable. If the pressure loss exceeds 10 psi [69 kPa], leaking connections shall be corrected using methods approved by the Engineer.

J. Tendon Protection - Within four hours after stressing, grout caps and other tendon openings shall be sealed. If acceptance of the tendon is delayed, all tendon openings and open ends of the anchorages shall be temporarily sealed. If tendon contamination occurs, the tendon shall be removed and replaced.

2.09 GROUTING

A. General - Before grouting operations commence, a joint meeting shall be held with the Contractor, Grouting Crew, Owner, and Engineering Inspection Team to discuss and understand the grouting operation plan, required testing and corrective procedures.
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B. Supplies - Before grouting operations start, an adequate supply of water and compressed air for clearing and testing the ducts, mixing and pumping the grout shall be provided. Where water is not supplied through the public water supply system, a water storage tank of sufficient capacity must be provided. A sufficient supply of grout material shall be available to complete the planned grouting operation.

C. Equipment
   1. General
      a. Grouting equipment shall consist 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. Pumping equipment shall have 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.
      b. An air compressor and hoses with sufficient output to perform the required functions shall be provided.
      c. Vacuum grouting equipment (volumetric measuring type) shall be provided prior to the start of grouting operations and retained on the job during the duration of tendon grouting operations.
   2. Mixer, Storage Hopper
      a. A high speed shear colloidal mixer shall be provided capable of continuous mechanical mixing to produce a homogeneous and stable grout free of lumps and un-dispersed 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.
      b. Water shall be added 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.
   3. Grout Pumping Equipment
      a. Grout pumping equipment capable of continuous operation shall be provided 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.
      b. Grout pumps will be positive displacement type and will provide a continuous flow of grout and will be able to maintain a discharge pressure of at least 145 psi [1 MPa]. Pumps will 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.
      c. A pressure gauge having a full scale reading of no more than 300 psi [2 MPa] will be placed at the duct inlet. If long hoses (in excess of 100 ft [30 m]) are used, two gauges shall be provided, one at the pump and one at the inlet.
d. The diameter and rated pressure capacity of the grout hoses must be compatible with the pump output.

4. Vacuum Grouting Equipment - Vacuum grouting equipment shall be provided at the job site concurrently with all pressure grouting operations. Vacuum grouting equipment must be the volumetric measuring type with the ability to measure a void and supply a measured volume of grout to fill the void.

5. Availability of Testing Equipment - Equipment for field-testing shall be available at the job site.

6. Stand-by Equipment: During grouting operations, a stand-by grout mixer and pump shall be provided.

D. Grouting Operations

1. General - Tendons shall be grouted in accordance with Section 8.6 of PCCM and the procedures set forth in the approved grouting operation plan and as noted herein.

2. Temperature Considerations - The maximum grout temperature must not exceed 90°F [32°C] at the grout inlet. Chilled water and/or pre-cooling of the bagged material to maintain mixed grout temperature below the maximum allowed temperature shall be used. Grouting operations shall be prohibited when the ambient temperature is below 40°F [4°C] or is 40°F [4°C] and falling.

3. Mixing and Pumping - The grout shall be mixed with a metered amount of water to produce a uniformly blended, homogeneous grout. The mix shall be continuously agitated until grouting is complete.

4. Injecting Grout
   a. All grout outlets shall be opened before starting the grouting operation. Tendons shall be grouted in accordance with the Grouting Operations Plan. Unless approved otherwise by the Engineer, grout shall be pumped at a rate of 16 feet (5 m) to 50 feet [15 m] of duct per minute. Normal grouting operations shall be conducted at a pressure range of 10 psi [69 kPa] to 50 psi [345 kPa] measured at the grout inlet; the maximum pumping pressure of 145 psi [1 MPa] at the grout inlet shall not be exceeded.
   b. Grout pumping methods shall 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. Grout shall be pumped through the duct and continuously discharged at the anchorage and grout cap outlets until all free water and air has been discharged and the consistency of the grout is equivalent to that of the grout being pumped into the inlet. The anchorage outlet shall be closed and a minimum of 2 gallons [7.5 liters] of grout from shall be discharged from the grout cap into a clean receptacle. The grout cap outlet shall then be closed.
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c. For each tendon, immediately after uncontaminated uniform discharge begins, a fluidity test shall be performed 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 given in Section 2.10 D (above). This cycle shall continue until acceptable grout fluidity is achieved. Properly discard grout used for testing fluidity.
d. After all outlets have been bled and sealed, the grout pressure shall be raised to ±75 psi [520 kPa] and the inlet valve sealed. Two minutes shall elapse to determine if any leaks exist. If leaks are present, they shall be fixed using methods approved by the Engineer. The above process shall be repeated until no leaks are present. If no leaks are present, the pressure shall be reduced to 5 psi [34 kPa] and a minimum of ten minutes shall elapse for any entrapped air to flow to the high points. After the minimum ten minutes period has expired, the pressure shall be raised as needed to discharge grout at each high point outlet to eliminate any entrapped air or water. The process shall be completed by locking-off at a pressure of 30 psi [207 kPa].
e. 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.
f. All waste grout and liquids shall be captured and disposed of properly.

5. Grouting Pressure - Under no circumstances shall the pumping pressure at the tendon inlet exceed 145 psi [1 MPa].

E. Temperature Considerations

1. When it is anticipated that the air temperature will fall below 32°F [0° C], ducts shall be kept free of water so as to avoid freeze damage to ducts. No grouting shall be done when the temperature of the grout is below 45°F [7° C]. The temperature of the concrete or air surrounding the tendon shall be maintained at 35°F [1° C] or above from the time grout is placed until the compressive strength of the grout, as determined from tests on 2 inch [50 mm] cubes cured under the same conditions as the in-place grout, exceeds 800 PSI [5.5 MPa].

2. No grouting shall be done when the temperature of the grout exceeds 90°F [32° C]. It may be necessary to chill mixing water or take special measures to lower the grout temperature.

F. Post-Grouting Operations

1. Valves, caps, and pipes at the inlet and outlet shall not be removed or opened until the grout has set. The filled ducts shall not be subjected to shock or vibration within 24 hours of grouting. All miscellaneous material (tie wire, duct tape, and so on) used for sealing grout cap connections shall be removed prior to carrying out further work to protect end anchorages. Repair any splits, holes, or other damage to exposed ducts.
2. All outlet and inlet openings shall be permanently sealed. The projecting pipe shall then be sealed with an inert (plastic or stainless steel) cap screwed or glued to pipe. Anchorages shall be protected to permanently prevent access of water or other aggressive agents.

G. Record of Grouting Operations - The Contractor shall keep a record of all grouting operations for each tendon installed, stressed and grouted. This shall include, but shall not necessarily be limited to the following:

1. Tendon or group of tendons grouted in one continuous operation.
2. Date grouted.
3. Number of days from stressing to grouting, per tendon
4. Type of grout mix and additives
5. Fluidity of grout (flow-cone) per batch for both newly mixed and 30 minute, rested grout
6. Density of grout per batch of fresh mix
7. Location of injection vent and direction of grout flow (note; injection vent may not necessarily be at an end anchorage).
8. Applied grouting pressure during normal pumping and maximum pressure sustained for two minutes after closing all vents grouting.
9. Theoretical volume of grout anticipated in order to fill the duct or ducts.
10. Actual quantity of grout in place in the duct(s) after grouting (For one grout mixing and injection operation, this is the quantity mixed less the quantity wasted at the vents, less the quantity remaining in the mixer and injection equipment).
11. Summarize any difficulties encountered and corrective action taken.
12. Witnesses to grouting operation (Contractor and Inspector)
13. Within 72 hours, the Contractor shall provide the Engineer with a complete copy of all tendon stressing and grouting operations.

2.10 QUALITY CONTROL AND QUALITY ASSURANCE FOR GROUTING

A. This section covers testing requirements for grouting materials, operations, equipment and personnel used in grouting post-tensioned tendons. Quality control and quality assurance shall comply with PTI M55.1-12 except as noted in this specification section.

B. Materials Certifications - The contractor shall provide written certification that all grout and grout ingredients meet any requirements of this specification.

C. Production Tests - The testing of production grout shall be carried out as described in the appropriate section (3.2) with the following minimum number of tests:

1. One pressure bleeding test (3.2.6) per day, the sample is to be taken at the mixer;
2. Two mud balance tests per day or when there is a visual or apparent change in the characteristics of the grout at the mixer and one at the duct outlet, as per PTI M55.1-12, Section 4.4.8;
3. Minimum of one strength test per day during grouting operations;
4. Minimum of two fluidity tests (flow cone)-one at the mixer and one at the duct outlet as per Section 3.2.5, repeat testing every 2 hours of grouting operations. The efflux
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- time shall be within 5 seconds of the values established during laboratory testing (Section 3.2).

D. Payment for Testing - All testing of components, materials and all laboratory and field tests required for this project shall be incidental to the price paid for post-tensioning.

METHOD OF MEASUREMENT
The quantity of post-tensioning tendons to be paid for under this Section will be measured by the number of individual tendons incorporated into the work, in accordance with the contract documents.

BASIS OF PAYMENT
The unit price bid for external tendons shall include all labor, materials and equipment required for furnishing, installing, stressing and grouting all 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, and outlets. This payment also includes corrosion inhibitors and approved lubricants in the tendon ducts for friction control and flushing lubricants or contaminants from the ducts.