POST-TENSIONING SPECIAL PROVISION REQUIREMENTS

The following is a detailed outline of the contents which are to be included in the Project-Specific Special Provision that is to be developed by the Bridge EOR for bridges that include post-tensioned elements. All work (materials, testing, procedures, etc.) outlined in the Special Provision shall be in accordance with AASHTO, PTI, and ASBI as referenced in this outline and Exhibit 4b. Note this Special Provision shall address requirements for the installation of horizontal post-tensioning in substructure elements. Vertical post-tensioning is not permitted.

Items that are *italicized* are instructional in nature and the EOR shall develop Special Provision content to address these items directly in accordance with the referenced industry standards. Items that are in normal print represent specific, required content of the Project Special Provision which the EOR is to develop; the EOR may add additional content, but must at a minimum include the required content.

In developing the Special Provision, do not simply reference PTI/ASBI or other reference documents to convey requirements; include the detailed requirements of these documents that are applicable to the specific component(s) in the Special Provision to facilitate efficient development and acceptance of required preconstruction documentation and effective construction administration.

OUTLINE OF SPECIAL PROVISION REQUIREMENTS

1.0 DESCRIPTION

- General: *Provide a description of the work covered by the Project-Specific Post-Tensioning Special Provision.*

- Qualifications of Personnel: *Provide qualification requirements for personnel. At a minimum, the Special Provision shall include the following requirements relative to involvement of qualified personnel:*

    - Perform all work for post-tensioning, including duct and hardware installation, prestressing steel installation, stressing, and installation of anchorage protection under the direct supervision of an individual certified as a PTI Level 2 Multistrand and Grouted PT Field Specialist.

    - Perform all grouting operations under the direct supervision of an individual certified as both a PTI Level 2 Multistrand and Grouted PT Field Specialist and an ASBI Certified Grouting Technician. The grouting foreman must have at least three (3) years of experience on previous projects involving grouting of a similar type and magnitude.

    - At least 25% of each crew performing post-tensioning operations or grouting operations shall be certified in PTI Level I Multistrand and Grouted PT Installation.

2.0 SHOP DRAWINGS AND CALCULATIONS:

Provide requirements for submittal of Shop Drawings and Calculations as outlined below:

- The Contractor shall submit signed and sealed Shop Drawings and Calculations showing complete details and designs of the post-tensioning system to SCDOT for review. Submittal of the Shop Drawings and Calculations shall meet the requirements outlined in the Standard Specifications unless noted otherwise in this Special Provision. Designs and details shall be sealed by a Professional Engineer registered in the State of South Carolina with a minimum of five (5) years of post-tensioning design and detailing experience.

- The Shop Drawings shall detail the installation and support of the ducts; location of grout inlets, outlets, and high point outlet inspection details; tendon geometry and locations complying with the plans and particular tendon system limitations; and other related details. The Shop Drawings shall indicate the approved post-tensioning system to be used and shall include system drawings and drawings for each component of the post-tensioning system including:

    - Wedges, wedge plates, bearing plates, trumpets, and local zone reinforcement
    - Permanent grout caps with installation accessories
    - Ducts, duct couplers, and typical connection details
    - Typical details for all vents and inspection points in the anchorages and along ducts
    - Duct inner diameter and outer diameter or other defining internal and external dimensions
    - Tendon types and sizes and duct types and sizes associated with different tendon lengths
    - Tendon ‘Z’ factors (offset of the center of gravity of the strand or bar inside the duct)
    - Friction coefficient and wobble details
    - Duct minimum radius of bending and method and spacing of duct supports
    - Methods of supporting all hardware before concreting
    - Minimum stressing tails for all tendon types
    - Minimum concrete blockout dimensions for equipment access and concrete cover
    - System seating losses (anchor set)
    - Minimum concrete strength for stressing

- Due to the congestion around the post-tensioning anchors, provide integrated drawings of post-tensioned elements including anchorages, tendons, and mild reinforcing required by the design shown. Include the following details on the integrated drawings:

    - Complete details of the anchorage system, anchorage protection, and any appurtenances for accommodating stressing equipment
    - All inlets, outlets, and inspection ports
    - Locations and dimensions of all duct high, low, and inflection points
    - Start and end points of all curve segments
    - Intermediate curve profiling points in each direction in which the tendon curves at intervals along the curve length. For compound curves, the vertical and horizontal curves shall start and end at the same locations whenever practical. Set out dimensions should be referenced off the formwork whenever possible.
    - Anchorage inspection details and permanent grout caps, protection system materials, and application limits

- Anchorage zone reinforcement as designed by the post-tensioning supplier
- Block out dimensions and locations
- Placement tolerances for post-tensioning components in accordance with Section 7.0 of this Special Provision

Section views showing member cross sections with fully dimensioned duct positions at critical locations shall be provided as necessary to completely and unambiguously define the tendon geometry. Show anchorage locations at the ends of members and at intermediate locations.

The Contractor shall be responsible for resolving conflicts between the different elements in the anchorage zone. Any shifting of the design reinforcing steel shall be approved by the EOR and SCDOT.

- The Shop Drawings and Calculations shall show complete details of tendon stressing. These details shall include sequence of stressing, jacking forces, calculated tendon elongations, gauge pressures, and jack calibrations. All of these shall be based on the actual post-tensioning system and hardware proposed for installation in the bent caps.

- Stressing Calculations shall be included for all tendons and shall include all assumptions, target stressing forces, and expected elongations based on nominal prestressing steel properties. Use a modulus of 28,500ksi for strand and 29,700ksi for Type II deformed bars. Elongations may be field-adjusted for the actual area and modulus of elasticity of the prestressing steel. The temporary stressing force, anchorage force, and maximum force along the tendon may not exceed the allowable stresses prescribed by the AASHTO LRFD Bridge Design Specifications. Calculate short-term losses due to friction, wobble, and wedge seating. Elongations shall be given to the nearest 1/16in and shall be provided before and after seating.

- The Shop Drawings shall include complete details of grouting materials, equipment, and procedures for approval by the EOR and SCDOT.

- The Shop Drawings shall include details and calculations for any temporary falsework which temporarily supports or is attached to a post-tensioned component. The design of the temporary falsework shall follow the AASHTO Guide Design Specifications for Bridge Temporary Works, 2017, with 2020 Interim Revisions.

3.0 TERMINOLOGY

Provide as needed to define terms throughout the Special Provision.

4.0 MATERIALS

Provide material specifications in accordance with the following:

Furnish materials that meet requirements of the most current versions of the following documents unless indicated otherwise: Post-Tensioning Institute's *Guide Specification for Grouted Post-Tensioning* (PTI/ASBI M50), Post-Tensioning Institute's *Specification for Grouting of Post-Tensioned Structures* (PTI M55.1), and the AASHTO LRFD Bridge Construction Specifications.

Reports for all testing performed in accordance with this specification, including detailed descriptions and results of each test performed, shall be submitted to SCDOT prior to, or as part of, the post-tensioning system shop drawing submittal.

4.1 Post-Tensioning System Components and Accessories:

Prestressing Steel: Furnish prestressing steel tendons conforming to *(EOR to select one of the following types based on design)*:

- Grade 270, low relaxation 7-wire strands conforming to the requirements of AASHTO M 203. Use strand produced by sources on SCDOT Qualified Products List 106.

- Grade 150, high strength, coarse thread bars meeting AASHTO M 275.

Tendon couplers, both bar and strand, are not allowed. Galvanized prestressing steel is not allowed.

The proper application of post-tensioning is predicated upon the use of suitable accessory materials. Details for the use of these materials shall be furnished by the manufacturer in connection with shop drawing submittals.

Provide details of all post tensioning accessory materials required to furnish a post-tensioning system following the minimum requirements for Protection Level 2 (PL-2), material requirements, and testing requirements specified in PTI/ASBI M50, PTI M55.1, and the AASHTO LRFD Bridge Construction Specifications. Describe in detail the materials to be used including, but not limited to:

- Post-Tensioning Anchorages – *include detailed information and requirements including but not limited to the following:*
  - *Development requirements for anchorage device and associated testing requirements*
  - *Accommodation of post-grouting inspection access for anchorage/grout outlet*
  - *Wedge/bearing plate requirements to facilitate proper function of anchorage and proper tendon alignment*

- *Any additional performance requirements of anchorage system necessary to achieve design intent (internal force distribution, bearing plate stresses, etc.)*

- Trumpets – *include detailed information and requirements including but not limited to the following:*
  - *Material specifications – Trumpets associated with anchorages shall be made of either ferrous metal or plastic. For plastic trumpets, the trumpet shall be made of high-density polyethylene or polypropylene.*
  - *Minimum thickness – The thickness of the trumpet at the duct end shall not be less than the thickness of the duct.*
  - *Connection details – Connections from the trumpet to the duct and the trumpet to the bearing plate shall have be airtight and watertight and shall be capable of withstanding at least 10ft of concrete fluid pressure.*

- Inlets, Outlets, Valves and Plugs
  - All inlets and outlets shall be equipped with pressure-rated mechanical shutoff valves or plugs.
  - *Include detailed information and requirements including but not limited to the following:*
    - *Material specifications*
    - *Required pressure ratings*
    - *Required sizes*
    - *Testing requirements*

- Permanent Grout Caps – *include detailed information and requirements including but not limited to the following:*
  - *Material specifications*
  - *Required pressure ratings*
  - *Means of sealing caps*
  - *Grout vent (required at the top of all grout caps)*
  - *Testing requirements*

- Ducts
  - Ensure that all connectors, connections and components of post-tensioning system hardware are airtight, watertight, and meet all pressure test requirements.
  - Joints in ducts shall not be used. Ducts shall be one continuous piece between connections to anchor plates.
  - *Include detailed information and requirements including but not limited to the following:*
    - *Size of Ducts – For strand tendons, ducts shall have a minimum cross-sectional area two-and-a-half times the cross sectional area of the prestressing steel based on the inside diameter of the duct. For prestressing bars, ducts shall have a minimum inside diameter of at least 1/2 in larger than the outside diameter of the bar, measured across the deformations.*
    - *Wall thickness of duct*
    - *Type of Duct – Duct material shall consist of Corrugated Metal or Corrugated Plastic only. Epoxy-Coated Metal Ducts shall not be used.*
    - *Performance requirements for ducts relative to proposed tendon geometry*

- *Testing requirements*
- *Shipping and Storage of Ducts – include requirements for protection of duct during shipping and storage and any requirements prior to incorporating into the bridge component.*

4.2 Post-Tensioning Grout:

- The Contractor shall use a Department-approved Class C (per PTI M55.1) pre-packaged grout that exhibits thixotropic properties and is stored in clearly-labeled, moisture-proof containers.

- Post-tensioning grout shall meet all material, storage, performance, testing, and other requirements of PTI M55.1.

- Documentation of all grout properties and testing performed in accordance with PTI M55.1 shall be provided to the EOR and SCDOT for approval prior to initiating grouting operations.

- Grout bags shall indicate application, date of manufacture, lot number, and mixing instructions. Any change of materials or material sources requires new testing and certification of the conformance of the grout with this specification.

- Flexible filler (microcrystalline wax) is not permitted.

- A copy of the Quality Control Data Sheet for each lot number and shipment sent to the job site shall be provided to the Contractor by the grout supplier and furnished to the EOR and SCDOT. Pre-packaged grout shall be used within a maximum of six months from the date of manufacture. Maintain grout fluidity in strict compliance with the grout manufacturer's recommendations and test with a flow cone.

- *Include detailed information and requirements for material properties and testing to ensure that grout used in post-tensioning operations meets the requirements specified in PTI M55.1, meets further requirements stated in this Special Provision, is compatible with post-tensioning supplier's requirements, and meets all performance requirements necessary to achieve the design intent.*

4.3 Samples for Testing:

Provide requirements for testing samples in accordance with PTI/ASBI M50 and PTI M55.1. Include a description of the items listed below, in accordance with the following criteria:

4.3.1 General: Testing shall conform to the applicable ASTM Specifications for the prestressing material used.

Contractor shall furnish all test samples and testing results to SCDOT as required by this Special Provision.

Job site or site referred to herein shall be considered the location where the prestressing steel is to be installed whether at the bridge site or a removed casting yard.

4.3.2 Prestressing Steel and Components: Samples for testing shall be furnished as described below for each manufacturer of prestressing strand and anchorage assemblies to be used on the project.

With each sample of prestressing steel strand or bar furnished for testing, submit the manufacturer's mill certification stating the minimum guaranteed ultimate tensile strength, modulus of elasticity, and prestressing steel area of the sample furnished.

The following samples of materials selected by the SCDOT at the plant or job site from the prestressing steel used for post-tensioning operations shall be furnished by the Contractor to SCDOT:

- For strand: three randomly selected samples, 5 ft. long, per manufacturer, per size of stand, per shipment, with a minimum of one sample for every ten reels delivered.
- For bars: three randomly selected samples, 5 ft. long, per manufacturer, per size of bar, per heat of steel, with a minimum of one sample per shipment.
- For anchorage assemblies: two samples of each size, per manufacturer, per heat of steel.

One of each of the samples furnished per heat will be tested by SCDOT at the Department's discretion. The remaining sample(s), properly identified and tagged, shall be stored by SCDOT for future testing in the event of loss or failure of the component represented to meet minimum strength requirements. For acceptance of the heat represented, test results shall show that 100% of the guaranteed ultimate tensile strength has been met.

4.3.3 Lots and Identification: A lot is that parcel of components as described herein. All anchorage assemblies of each size from each mill heat of steel, all bars of each size from each mill heat of steel, and all strand from each manufactured reel to be shipped shall be assigned an individual lot number and shall be tagged in such a manner that each such lot can be accurately identified at the job site. Records shall be submitted to SCDOT identifying

assigned lot numbers with the heat or reel of material represented. All unidentified prestressing steel or anchorage assemblies 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 SCDOT, from the manufacturer, for each lot number and shipment sent to the job site.

4.4 Approval of Materials: The approval of any material by the SCDOT shall not preclude subsequent rejection if the material is damaged in transit or later damaged or found to be defective.

5.0 TESTING BY THE CONTRACTOR

Testing in this section is in addition to that required in Section 4. Provide the requirements for verification testing to be performed by the Contractor/Post-Tensioning Supplier. At a minimum, the following tests shall be performed:

5.1 Tendon Modulus of Elasticity: This test will not be required if the Contractor can demonstrate, to the satisfaction of the EOR and SCDOT, valid results for the tendon modulus of elasticity from previous projects or based on results from manufacturer tests. Such results must be for the same type of strand, size, material, and complement of strands per tendon as required for this project and must have been performed under test conditions equal to or better than those described below.

If testing is required, for the purpose of accurately determining the tendon elongations while stressing, the Contractor shall bench test two samples of each size and type 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 shall be at least 30 feet and the tendon duct shall be at least 2 inches clear of the tendon all around. The test procedure shall consist of stressing the tendon at an anchor assembly with a load cell at the dead end. The test specimen shall be tensioned to 80% of ultimate in ten increments and then detensioned from 80% of ultimate to zero in ten decrements. For each increment and decrement, the gauge pressure, elongations and load cell force shall be recorded. Elongations of the tendon shall be noted for both ends and the central 26 feet and shall be measured to an accuracy of 1/32 inch. The elongations shall be corrected for the actual anchorage set of the dead end.

The modulus shall be calculated as follows:

$$E = \frac{P \times L}{A \times dl}$$

where:

P = force in tendon,

L = distance between pulling wedges and dead end wedges or exact length in center 26 feet of the tendon.

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

dl = tendon elongation for load P.

The theoretical elongation shown on the post-tensioning shop or working drawings shall be reevaluated by the Contractor using the results of the test and corrected when the modulus of elasticity from the bench test varies from the modulus of elasticity used for shop or working drawings by more than 1%. Revisions to the theoretical elongations shall be submitted to the EOR and SCDOT 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 EOR and SCDOT.

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

The apparatus and methods used to perform the test shall be proposed by the Contractor and be subject to the approval of the EOR and SCDOT. Furthermore, this test shall be conducted by the Contractor in the presence of SCDOT or their representative.

5.2 In Place Friction Test: This test is intended to demonstrate that the friction characteristics, losses, and resulting tendon forces are in agreement with the design assumptions.

For the purpose of verifying friction loss the Contractor shall test, in place, the first tendon installed of each size and type which is at least 100 feet long. Size is defined as the size and number of strands in each tendon. Type is defined as to both prestressing and duct material.

The test procedure shall consist of stressing the tendon at an anchor assembly with a load cell at the dead end. The test specimen shall be tensioned to 80% of ultimate tendon strength in eight equal increments and detensioned in eight equal decrements. For each increment and decrement, the gauge pressure, elongations and load cell force shall be recorded. Account shall be taken of any wedge seating in both the live end (i.e., back of jack) and the dead end (i.e., back of load cell) and of 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, care shall be taken to keep an accurate account of the elongation at the jacking end allowing for intermediate wedge seating and slip of the jacks' wedges.

The contractor shall reevaluate the theoretical elongations shown on the post-tensioning installing drawings using the results of the in-place friction test(s) and modify as necessary. Submit revisions to the theoretical elongations to the EOR and SCDOT. Friction-reducing agents may be used with approval from the EOR provided that the same friction-reducing agents are used on all tendons of the same type and length for which the in-place friction test was performed.

Tendon elongations shall be measured and recorded to the nearest 1/16 in and shall fall within 7% (for tendons with a length of 40ft or more) or 7% + 1/4in (for tendons with a length less than 40ft) of the theoretical elongations shown on the approved installation drawings, modified if necessary for the actual modulus of elasticity and prestressing steel areas shown on the prestressing steel mill certificates. If, for the

Contractor's expected friction coefficients, the elongations fall outside this range, the Contractor will be required to investigate the reason and make revisions to his post-tensioning operations such that the final tendon forces are in agreement with the Plans.

In reconciling theoretical and actual elongations, the value of the expected friction and wobble coefficients shall not be varied by more than ±10%. Significant shortfall in elongations is indicative of poor duct alignments and/or obstructions which the Contractor shall be required to correct or compensate for in a manner to be proposed by the Contractor and reviewed and approved by the EOR at no additional cost to the Department.

One successful friction test for each type and size of tendon (tendon group) of length 100ft or longer will be required for the project.

If, during the course of routine stressing operations, there are irreconcilable differences between forces and elongations, or other difficulties, the EOR reserves the right to require additional in place friction tests regardless of tendon length.

The apparatus and methods used to perform the test shall be submitted by the Contractor to the EOR and SCDOT for approval. This test shall be conducted by the Contractor in the presence of the EOR and/or SCDOT.

Correction or adjustment of elongations as a consequence of the results of the friction test are the responsibility of the originator of the stressing and elongation calculations.

5.3 Test Reports Required: Two test reports of the "Tendon Modulus of Elasticity Test" shall be submitted to the EOR and SCDOT at least 30 days prior to installing the tendon.

Two test reports of the "In Place Friction Test" shall be submitted to the EOR and SCDOT within 2 weeks after successful installation of the test tendon.

5.4 Application of Test Results: The theoretical elongations shown on the post-tensioning shop or working drawings shall be reevaluated by the Contractor using the results of the tests for Tendon Modulus of Elasticity and In Place Friction as appropriate and corrected as necessary. Revisions to the theoretical elongations shall be submitted to the EOR and SCDOT for approval.

6.0 PROTECTION OF PRESTRESSING STEEL

Provide details of the provisions for the protection of prestressing steel, hardware, duct, and accessory components during the timeframes specified below. At a minimum, these provisions shall meet the requirements specified in PTI/ASBI M50.

- *Shipping, Handling, and Storage – include detailed information and requirements including but not limited to the following:*
  - *Protection from physical damage, exposure, and corrosion*
  - *Use of and permissible type of corrosion inhibitor*
  - *Condition of prestressing steel prior to incorporation into the project*
  - *Identification, tracking and maintenance of traceability*

- *During Installation in the Structure – include detailed information and requirements including but not limited to the following:*
  - *Condition of the prestressing steel after stressing and prior to grouting*
  - *Required maximum timeframe between stressing and grouting operations and measures to be taken to protect the steel prior to grouting*

Field welding in the vicinity of prestressing steel, hardware, ducts, and accessory components prior to and after installation is prohibited.

7.0 FABRICATION

General – All post-tensioning anchorages, ducts, vent pipes, miscellaneous hardware, reinforcing bars, and other embedments shall be accurately and securely fastened at the locations shown on the Plans or on the approved Shop Drawings.

Provide requirements for the fabrication of the post-tensioning system to address the following items at a minimum:

- Ducts – *include detailed information and requirements including but not limited to the following:*
  - *Performance requirements relating to positioning, alignment, and condition of ducts prior to concrete placement*
  - *Measures required to prevent entry of water and debris into duct system prior to final tendon grouting*
  - *Required minimum spacing of fastenings and duct supports to prevent movement, displacement, or damage from concrete placement and consolidation activities.*

- Joints and Connections – *include detailed information and requirements relating to the alignment and sealing of joints and connections*

- Grout Inlets and Outlets
  - All ducts and anchorage assemblies for permanent post-tensioning shall be provided with grout inlets and outlets as required for the injection of grout after prestressing. Grout inlets and outlets shall be placed at locations shown on the approved installation drawings. All grout inlets and outlets shall be equipped with positive shutoff devices. Grout tubes shall be extended out of the concrete member to allow for proper closing of the valves. As a minimum, ducts shall be vented at the following positions:
    - Top of the tendon anchorage
    - Top of the grout caps
    - At the high points of the duct when the vertical distance between the highest and lowest point is more than 20 inches
    - At all low points
    - At a distance not to exceed 36” from high points in both directions

  - All ducts shall be pressure-tested prior to concrete placement in the forms. In the presence of the EOR, pressurize duct to 7.5 psi and lock-off outside air source. Record pressure loss for one minute. If the pressure loss exceeds 0.75 psi, or 10%,

find and repair leaks in the duct assembly using repair methods approved by the EOR and retest.

- *Include additional detailed information and requirements including but not limited to the following:*
  - *Means of tube, vent, and valve placement to facilitate grouting operations*
  - *Seal and cap requirements*

- Tolerances – *include tolerances for post-tensioning components including but not limited to the following:*
  - *Ducts (horizontal and vertical location)*
  - *Anchorages (horizontal and vertical location, entrance/exit angle)*
  - *Anchorage confinement reinforcing*
  - In the event of conflicts between the reinforcement and post-tensioning duct, in general, the position of the post-tensioning duct shall prevail, and the reinforcement shall be adjusted locally to the approval of the EOR.

8.0 PLACING CONCRETE

8.1 Precautions: *Specify methods and precautions to be taken when placing and consolidating concrete so as to not displace or damage the post-tensioning ducts, anchorage assemblies, splices, connections, reinforcement, or other embedments.*

8.2 Proving of Post-Tensioning Ducts: Upon completion of concrete placement the Contractor shall prove that the post-tensioning ducts are free and clear of any obstructions or damage and will be able to accept the intended post-tensioning tendons by passing a torpedo of suitable rigid material through the ducts. The torpedo shall have the same cross-sectional shape as the duct, be ¼ inch smaller all around than the clear, nominal inside dimensions of the duct. No deductions to the torpedo section dimensions shall be made for tolerances allowed in the manufacture or fixing of the ducts. For curved ducts, the length shall be determined by the Contractor such that when both ends touch the outermost wall of the duct, the torpedo is ¼ inch clear of the innermost wall; but it need not be longer than 2 feet. If the torpedo will not travel completely through the duct, the post-tensioned component shall be rejected, unless a workable repair can be made to clear the duct, all to the satisfaction of the EOR and SCDOT. The torpedo shall be passed through the duct easily, by hand, without resorting to excessive effort or mechanical assistance.

8.3 Problems and Remedies: If the torpedo will not travel completely through the duct, the duct shall be cleared and repaired by means specified in the project quality plan and approved by the EOR and SCDOT.

9.0 INSTALLING TENDONS

General – Protect all prestressing steel against physical damage and corrosion at all times – from manufacture to final grouting. Prestressing steel that has been damaged shall be rejected. Causes for rejection include, but are not limited to, yielding, pitting, nicks, and exposure to excessive heat from adjacent welding or cutting operations. Normal wedge marks in the anchorage region do not constitute damage to the strand. Prestressing steel to

be installed in the ducts shall be free of deleterious material such as dirt, grease, oil, wax, or paint. Wires shall be bright, uniformly colored, and have no foreign matter on their surfaces. Slight rusting, provided it is not sufficient to cause pitting visible to the unaided eye, shall not be cause for rejection.

Bars shall be free of defects injurious to its mechanical properties and have a workmanlike finish. They shall be free from loose rust, loose mill scale, dirt, paint, oil grease or other deleterious materials.

Installation of strand tendons in ducts prior to concrete placement shall not be allowed. Install prestressing bars into ducts before concrete placement when feasible.

No permanent tendons shall be installed prior to the completion of testing as required by these specifications or Plans, except for the "In Place Friction Test" where only the tendon to be tested shall be installed prior to successful completion of the test.

Cutting of tendons shall be done with an abrasive saw or similar. Flame cutting shall not be allowed.

Provide additional requirements for installing post-tensioning tendons within the ducts for the project-specific post-tensioning application(s). Include measures of corrosion protection to be implemented in the event that the time limits specified in Section 6 between installation and grouting of the tendon will be exceeded. Include acceptance criteria that meets or exceeds the requirements of PTI/ASBI M50.

10.0 POST-TENSIONING OPERATIONS

Provide requirements for the post-tensioning operations to address and/or include the following:

- General – Post-tensioning forces shall not be applied until the concrete has attained the specified compressive strength as determined by cylinder tests. Stress all prestressing steel with hydraulic jacks of sufficient capacity to the forces shown on the approved installation drawings, or as otherwise approved by the EOR. Conduct all stressing operations in the presence of SCDOT or their representative. Do not use single strand jacks to stress strand tendons except for special cases at the discretion of the EOR.

- Stressing Tendons – *include detailed information and requirements including but not limited to the following:*
  - Maximum Stress at Jacking – *provide limits on stresses during jacking*
  - Initial and Permanent Stresses – *provide limits for initial stress values and requirements for permanent stress in the post-tensioning steel*
  - Stressing Sequence – *provide any necessary instructions relating to stressing sequence*

- Stressing Equipment – Equipment for tensioning the tendons shall be furnished by the manufacturer of the post-tensioning system (tendons, hardware, anchorages, etc.).
  - Stressing Jacks and Gauges – Each jack used to stress tendons shall be equipped with a pressure gauge for determining the jacking pressure. The pressure gauge shall have an accurately reading dial at least 6 inches in diameter. Pressure gauges

or electronic pressure transducers with digital indicators shall indicate the load directly to 1% of the maximum gauge or sensor/indicator capacity or 2% of the maximum load applied, whichever is smaller.

- Calibration of Jacks and Gauges – Calibrate each jack and two gauges as a unit. Separate calibrations shall be performed with the jack in the ¼, ½, and ¾ stroke positions. At each pressure increment, average the forces from the three stroke positions to obtain a standardized force. An independent laboratory shall perform the initial calibration of the jacks and gauges using a proven load cell and shall prepare the certified calibration report(s). Use load cells calibrated within the past 12 months to calibrate the stressing equipment every 6 months. For each jack and gauge unit used on the project, the Contractor shall furnish certified calibration charts and curves to the EOR and SCDOT prior to stressing the first tendon. Supply documentation denoting the load cell(s) calibration date and traceable to NIST (National Institute of Standards and Technology) along with the jack/gauge calibration.

  Provide the EOR and SCDOT with certified calibration reports prior to the start of stressing and every 6 months thereafter or as requested. Calibrations after the initial calibration by load cell may be done with a master gauge. Provide the master gauge to SCDOT in a protective waterproof container capable of preserving the calibration of the master gauge during shipping. Provide a hydraulic manifold that ensures quick and easy connection of the master gauge to any jack on site to verify the production gauge readings. The master gauge shall be calibrated in tandem with each jack/gauge calibration preformed for the project and delivered to SCDOT, together with all calibration data. Alternatively, if all gauges were calibrated to a current calibrated (NIST) dead-weight tester, the master gauge does not need to be calibrated in tandem. The master gauge will remain in the possession of SCDOT for the duration of the project

  Any jack repair, such as replacing seals, shall be cause for recalibration using a load cell.

- Elongation and Agreement with Forces

  - The post-tensioning operation shall be so conducted that the forces being applied to the tendon and the elongation of the post-tensioning tendon can be measured at all times.

  - All tendons shall be stressed to the corresponding forces shown on the approved installation drawings as determined by gauge pressure readings. Do not stress tendons by matching the theoretical elongations.

  - Tendon elongations shall be measured and recorded to the nearest 1/16 in and shall fall within 7% (for tendons with a length of 40ft or more) or 7% + 1/4in (for tendons with a length less than 40ft) of the theoretical elongations shown on the approved installation drawings, modified if necessary for the actual modulus of elasticity and prestressing steel areas shown on the prestressing steel mill certificates. Tendons shall not be overstressed to achieve the theoretical elongation.

- If actual elongations fall outside the allowable range, the entire operation shall be checked, and the source of error determined and remedied before proceeding further.

- In coordination with the post-tensioning system supplier, the Contractor shall develop and propose measures to correct or compensate for deviations of calculated-versus-measured elongations for approval by the EOR and SCDOT. Measures to correct or compensate for deviations shall be implemented only after approval by the EOR and SCDOT.

- If elongations fall short by more than allowed by this Special Provision and the Contractor cannot determine the cause, verify the fixed-end force with a stressing jack if accessible. If the fixed-end force is lower than theoretical, the tendon is still acceptable without further action if the average of all the tendon forces of the member cross sections have a final post-tensioning force of at least 98% of the design total post-tensioning force. If the fixed-end force is higher than theoretical, the tendon is acceptable without further action.

- When strand tendons are intended to be single-end stressed, but both ends are accessible and the fixed-end force is found to be lower than theoretical through the use of a lift-off test, additional stressing from the fixed end shall be permitted with EOR approval if the additional calculated elongation is at least 0.5in.

- *Provide additional guidance as appropriate for measurement of elongations and measures to be taken to resolve discrepancies.*

- Friction Testing– *Provide for field determination of observed/actual friction compared to design values and provide means for adjusting post tensioning operations to achieve the final tendon force which meets the design intent.*

- Wire Failures in Post-Tensioning Tendons *(if applicable) – Provide conditions for acceptance of tendons with failed wires (due to breakage or slippage during stressing) and/or allowance for alternative means to restore force lost due to wire failure.*

- Cutting of Post-Tensioning Steel – *Provide directions for the cutting of post-tensioning steel. Post-tensioning steel shall be cut by an abrasive saw within 1/2in to 3/4in away from the wedge, unless other details and dimensions are shown on the approved installation drawings.* Flame cutting of post-tensioning steel is not allowed. Install the grout cap immediately after cutting. Do not cut tendon tails prior to acceptance by SCDOT.

- Record of Stressing Operations: The Contractor shall keep a record of the following post-tensioning operations for each tendon installed:

  - Project name and ID number;
  - Contractor and/or subcontractor;
  - Approved PT Installation Drawing date and revision number;
  - Tendon location, size, and type;
  - Date tendon was installed in ducts;
  - Reel number(s) for strands and heat number for bars;

- Assumed and actual weighted cross-sectional area based on mill certificates;
- Assumed and actual modulus of elasticity based on mill certificates;
- Date Stressed;
- Stressing operator(s) name;
- Jack and gauge numbers for each stressing end;
- Required jacking force;
- Target and actual gauge pressures;
- Elongations (theoretical and actual)
- Anchor sets (anticipated and actual)
- Stressing sequence (ie., tendons before and after);
- Stressing mode (one end/ two ends/ simultaneous);
- Witnesses to stressing operation (Contractor and inspector);
- Daily temperature and relative humidity;
- Use of temporary corrosion inhibitor, if applicable;
- Any other relevant information shall also be recorded. The Contractor shall provide the EOR and SCDOT with a complete copy of all stressing records at the conclusion of that day's stressing operations.

- Tendon Protection – Seal all duct openings other than installing anchorage caps within four hours after stressing. Install anchorage caps after the tendon has been accepted. If acceptance of tendon will be delayed more than one day after stressing, immediately provide temporary weatherproofing of tendons at open ends of anchorages. If tendons and anchorages are temporarily weatherproofed, install anchorage caps within 1 day of tendon being accepted. If tendon contamination occurs and if directed by SCDOT, remove and replace the tendon.

11.0 GROUTING OPERATIONS

Provide requirements for the grouting operations in accordance with the requirements of PTI/ASBI M50 and PTI M55.1 to address and/or include the following:

11.1 General information – Within 20 calendar days after installation of the post-tensioning steel, ducts shall be grouted in accordance with these specifications. Except when approved by the EOR and SCDOT in writing, failure to grout tendons within the 20 calendar days specified shall result in stoppage of the affected work and no invoices shall be processed for payment of that affected work.

After stressing and prior to grouting, tendons shall be protected against corrosion or harmful effects of debris by temporarily plugging or sealing all openings and vents until the tendon is grouted.

After stressing and prior to grouting, duct air tests shall be performed on each tendon to identify any leaks in the duct system so they can be addressed before grouting. Pressurize tendons to 30 psi, lock off the outside air source, and inspect for leaks. Locate and repair any leaks and retest. *Provide criteria for the duct air test that is appropriate for the particular post-tensioning system. General criteria of approximately 1 minute and less than 50% pressure loss has been used for PL2 tendons.*

When stressing has been completed and the stressed tendons have been accepted by the SCDOT or their representative, the annular space between the tendons and the duct shall be grouted.

11.2 Grouting Operations Plan – Submit a grouting operations plan for approval at least four weeks in advance of the start of construction of post-tensioned elements. Written approval of the grouting operations plan by the EOR and SCDOT is required before any grouting of the permanent structure takes place. At a minimum, the plan shall address and provide procedures for the following items:

- Names and proof of training for the grouting crew and the crew supervisor in conformance with this specification;
- Type, quantity, and brand of materials used in grouting including all certifications required;
- Type of equipment furnished, including capacity in relation to demand and working condition, as well as back-up equipment and spare parts;
- Types and locations of inlets and outlets;
- Duct cleaning methods prior to grouting;
- Duct pressure test and repair procedures;
- General grouting procedure;
- Method to be used to control the rate of flow within ducts;
- Theoretical grout volume calculations;
- Mixing and pumping procedures;
- Direction of grouting;
- Sequence of use of the inlets and outlet pipes;
- Procedures for handling blockages;
- Procedures for possible regrouting or post-grouting repair.

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

11.3 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.

11.4 Equipment and Supplies – *Include detailed information and requirements including but not limited to the following:*

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, and testing equipment. Provide pumping equipment with sufficient capacity to ensure that the post-tensioning duct for the longest tendon on the project can be grouted without interruption at the required rate of injection in not more than 30 minutes once mixing has commenced. The equipment shall be able to pump mix grout in a manner which will comply with all the provisions specified herein. 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.

11.4.2 Mixer, Storage Hopper, and Screen – *Provide requirements for mixer and storage tank to achieve proper measuring and mixing of materials, agitation during holding, and continuous delivery of a homogeneous, stable grout, free of lumps and undispersed cement, to the pumping equipment. At a minimum, include the following:*

The grout shall use a high-speed shear colloidal mixer with a storage hopper between the mixer and the pump. The storage hopper shall be fitted with an agitator to keep the grout moving continuously before it is pumped into the duct; the hopper must be kept at least partially full. The grouting equipment shall use a gravity feed to the pump inlet from the agitator attached to and directly over it.

The grouting equipment shall contain a screen having maximum clear openings of 3/16in to screen the grout prior to its introduction into the grout pump or storage hopper. The screen shall be located between the mixer and storage hopper and shall be easily accessible for inspection and cleaning. The screen shall be inspected periodically during grouting operations. If lumps of cement remain on the screen, the mixture is not suitable for grouting.

11.4.3 Grout Injection Equipment – *Provide requirements for grout pumping equipment to inject post-tensioning grout into the ducts. At a minimum, include the following:*
Provide pumping equipment capable of continuous operation with minimal variation of pressure and which includes 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 shall be fitted with a valve that can be closed off without loss of pressure in the duct. The use of compressed air to aid in the pumping of grout is not permitted.

Grout pumps shall be positive displacement type, shall provide a continuous flow of grout, and shall be able to produce an outlet pressure of at least 145 psi. The capacity will be such that an optimal rate of grouting can be achieved.

Pumps shall be so constructed and have seals adequate to prevent oil, air, or other foreign substances from entering into the grout and to prevent loss of grout or water.

Piping to the grout pump shall incorporate a sampling tee with stopcock and shall minimize the number of bends, valves, and changes in diameter.

A pressure gauge having a full scale reading of no more than 300 psi shall be placed at some point in the grout line between the pumping outlet and 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 shall be compatible with the pump output, the

assumed maximum pressure, and the length needed. Ensure that grout hoses are securely connected to pump outlets, pipes, and inlets of the duct.

11.4.4 Vacuum Grouting Equipment **–** *Provide requirements for vacuum grouting equipment to be used in filling voids identified during post-grouting inspections. At a minimum, include the following:*

Provide vacuum grouting equipment meeting these minimum requirements:

- Volumeter for measurement of void volume;
- Vacuum pump with a minimum capacity of ten cubic feet per minute and equipped with a flow meter, graduated hopper, or other acceptable means approved by the EOR capable of measuring the amount of grout being injected;
- Manual colloidal mixers, manual high speed shear mixers, or other mixing methods recommended and approved by the grout manufacturer, in writing, for the specific project covered by this Special Provision for voids less than 5.5 gallons in volume. However mix a minimum of one full bag of grout regardless of the size void to be grouted.
- Standard colloidal mixers for voids 5.5 gallons and greater in volume.

11.5 Stand-by Equipment: *Specify stand-by equipment to be provided during grouting operations. At a minimum, include the following:*

During grouting operations, the Contractor shall provide a stand-by colloidal grout mixer, pump, and hoses. Where water is not supplied through the public water supply system, a water storage tank of sufficient capacity must be provided.

11.6 Field trial tests – *Provide detailed requirements and guidance for field trial tests in accordance with PTI M55.1 in order to demonstrate that the grouting equipment, methods, and procedures are appropriate. As part of the field trial tests, establish target efflux time values for the equipment and materials that are to be used for production. At a minimum, include requirements for:*

- *Grout strength test*
- *Volume change test*
- *Pumpability and fluidity tests*
- *Schupack pressure bleed test*
- *Chloride ion test*

11.7 Grout Production Tests – *Provide detailed requirements and guidance for grout production tests in accordance with PTI M55.1. At a minimum, include the following:*

- *Schupack pressure bleed tests*
- *Wet density tests*
- *Fluidity tests*
- *Chloride ion tests*

11.8 Mixing of Grouts – *Provide proportioning and testing requirements in accordance with PTI M55.1 to produce a homogeneous grout and achieve flowability and pumpability required for the specific application.*

For quality control on site, the flowability of the grout shall be checked in accordance with ASTM C939. ASTM C939 shall be modified by the following revision. The efflux time of the grout sample immediately after mixing shall be as established by testing at the maximum and minimum water amounts; however, no less than 5 seconds and no more than 30 seconds. Grouting shall not proceed until this test has been passed. After mixing and resting without agitation for a period of 30 minutes, the efflux time shall not exceed 30 seconds following 30 seconds of remixing.

11.9 Preparation for Grouting – Immediately prior to grouting, ducts shall be blown with oil-free compressed air to remove water and debris blockages that may interfere with the injection. All inlets and outlets shall be checked to ensure they are capable of accepting injection of the grout by blowing through the system with oil-free compressed air and proving each inlet and outlet in turn.

11.10 Grouting Operations - *Provide requirements for grout injection into the ducts in accordance with PTI M55.1, including, but not limited to, the following:*

- All grout vents shall be open, and drains closed when grouting starts.
- Grout shall be injected from the tendon lowest point or the lowest end of the tendon in an uphill direction. The grout shall be used within 30 minutes of the first addition of water to ensure the flowability of grout.
- A continuous one-way flow of grout shall be maintained within the grouting stage.
- A high speed shear (colloidal) type mixer shall be used to mix the grout
- Grouting of a tendon or designated group of tendons shall be performed in one operation.
- *Provide direction on the operation of valves at vent and drain locations during grouting and at the completion of grouting.* The outlet at the end of the tendon shall not be permanently closed until the wet density passes the previously established wet density range.
- *Specify the grout injection rate*
- *Specify the maximum pumping pressure and recommended pressure during grouting operations*
- The inlet shall be sealed off while maintaining the pumping pressure once the tendon duct is completely filled and all outlets have been closed. All vent, inlet, and outlet tubes shall be elevated above the level of the tendon where they are connected until the grout has hardened to help capture any entrapped air or bleed water.

- *Specify the means of observing vents and operating valves to ensure that ducts are completely filled with grout.*

- *Specify the procedure to be used in the event that the actual grouting pressure exceeds the maximum allowed.*

- *Specify the procedure to be used in the event that one-way flow of grout cannot be maintained.*

- Flushing of the PT system with water shall not be permitted.

11.11 Temperature Restrictions – *Provide minimum and maximum temperatures for performing normal grout operations and, if applicable, measures to be taken if grouting is to be done outside of that temperature range in accordance with PTI M55.1 and guidance from the post-tensioning grout manufacturer.*

11.12 Post-Grouting Operations, Inspection, and Finishing – *Provide requirements for measures to be taken after grouting including inspection of grouted tendons; repairs of splits, holes, or other damage to exposed ducts; finishing of the concrete surface in the vicinity of grout ports, and placement of pourbacks. At a minimum, include the following:*

- 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 inlets or outlets located at the anchorages. Depending on the geometry of the grout inlets, drilling may be required to penetrate to the inner steel 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 SCDOT using borescopes or probes. If unsuitable grout is observed, the Contractor shall submit a repair procedure for approval by the EOR and SCDOT. Within four hours of completion of the inspections or repairs, 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 using repair methods approved by the EOR and SCDOT. Remove inlets and outlets to a minimum depth of 1 inch below the surface of the concrete and permanently seal and fill with epoxy flush to the concrete surface using procedures approved by the EOR and SCDOT.

- If tendon grouting operations were prematurely terminated prior to filling the tendon, drill into inlets, outlets, and/or drains to explore the voided areas with a borescope. Probing is not allowed. Determine the location and extent of all voided areas. Install grout inlets as necessary using a method approved by the EOR and SCDOT and fill the voids using volumetric measuring vacuum grouting equipment.

- Post-grouting inspection shall be performed for all tendons.

11.13 Grouting Report - *Provide requirements for the development and submission of a grouting report to be completed after each grouting operations. At a minimum, include the following:*

- Provide a grouting report signed by the contractor within 72 hours of each grouting operation for review by the EOR and SCDOT.

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

- Information to be noted in the records shall include but not necessarily be limited to the following:

    - Identification of tendons grouted
    - Date grouted
    - Number of days from tendon installation to grouting
    - Type of grout
    - Grout supplier and grout lot numbers
    - Injection end and applied grouting pressure
    - Ratio of actual to theoretical grout quantity
    - Number of bags of grout mixed
    - Total quantity of water used to mix the grout
    - Summary of production testing performed
    - Summary of any problems encountered and corrective action taken.

.

12.0 PROTECTION OF END ANCHORAGES (POST-TENSIONING ENCASEMENT)

Provide details of the provisions for the protection of end anchorages in accordance with PTI/ASBI M50 which address and/or include the following:

- Surface Cleaning – *Provide requirements for cleaning exposed end anchorages and other metal accessories within the limits of the post-tensioned encasement area.*

- Application of Bonding Compound – *Provide requirements for application of bonding compound within the post-tensioned encasement area,*

- Encasement of End Anchorage – *Provide requirements for materials and procedures for encasement pour-back to encapsulate the post-tensioning end anchorage as appropriate for the particular post-tensioning system. Pourbacks shall be constructed with an approved epoxy grout. Large pourbacks that would preclude the use of epoxy grout shall be constructed with reinforced concrete. Unreinforced concrete or non-shrink grout pourbacks are not permitted.*

- Anchorage Coating System
    - *Provide requirements for an elastomeric coating system to be applied to all exposed surfaces pourbacks not exposed to traffic.*
    - *Provide requirements for coating exposed surfaces of pourbacks exposed to traffic with an approved high-molecular-weight methacrylate.*