

PART 1 GENERAL

I DESCRIPTION

A) Scope of Work

- 1) The Work specified in this Section consists of manufacturing, storing, transporting, and supplying complete RockHardscp®, mechanically joined, steel reinforced, gasketed segments for final liner rings in tunnels, including necessary labor, materials, tools and equipment to manufacture corrosion resistant segments to obtain a water tight tunnel, that are capable of rapid erection within the Tunnel Boring Machine, and that will resist loads imposed during manufacture, handling, transport and installation. Also included is the repair of RockHardscp® segments of defects.
- 2) RockHardscp® segments and associated items have been designed for anticipated ground and water loads and environmental conditions on the completed tunnel. Contractor shall ensure that the segments are compatible with its selected construction equipment, means, methods, and procedures including, but not limited to, handling, erecting, jacking and grouting. Contractor shall submit any segment design modifications required to ensure this compatibility and include all costs related to such modifications in the bid price. RockHardscp® manufacturer shall have final approval on RockHardscp® segment design.
- 3) Utilize tapered rings to provide changes in tunnel alignment and elevation.
- 4) Refer to Excavation by Tunnel Boring Machine, for requirements for installation and erection of the lining.
- 5) All RockHardscp® quality control testing associated with the manufacture of SCP segments is the responsibility of the SCP segment manufacturer.

B) Definitions

- 1) RockHardscp® Segmental Lining: A structural lining comprised of mechanically connected, gasketed RockHardscp® segments grouted in place, which serves as both initial support and final lining.
- 2) RockHardscp® Precast Segment: A RockHardscp® structural casting in an arc shape, which when installed in the tunnel with other segments, forms a continuous ring or support.

C) Products furnished under this section

- 1) RockHardscp® segments, gaskets, mechanical connectors, compression packings, and other lining appurtenances.

II QUALITY ASSURANCE

A) Applicable Codes and Standards

- 1) American Society for Testing and Materials (ASTM)
 - (i) ASTM A36: Carbon Structural Steel
 - (ii) ASTM A615: Standard Specification for Deformed and Plain Billet-Steel Bars for Segment Reinforcing.
 - (iii) ASTM A185: Steel Welded Wire Fabric, Plain, for Segment Reinforcement.
 - (iv) ASTM C117: Mineral Aggregates, Fillers
 - (v) ASTM C136: Mineral Aggregates, Fillers
 - (vi) ASTM C 33: Standard Specification for Concrete Aggregates
 - (vii) ASTM C307: Tensile Strength of RockHardscp® and Polymer Mortars.
 - (viii) ASTM C579: Compressive Strength of RockHardscp® and Polymer Mortars.
 - (ix) ASTM C580: Modulus of Elasticity of RockHardscp® and Polymer Mortars.
 - (x) ASTM C1166: Flame Propagation of Dense and Cellular Elastomeric Gaskets and Accessories
 - (xi) ASTM 395: Rubber Property – Compression Set
 - (xii) ASTM D412: Rubber Properties in Tension
 - (xiii) ASTM D471: Rubber Property – Effects of Liquids
 - (xiv) ASTM D518: Rubber Deterioration – Surface Cracking
 - (xv) ASTM D573: Rubber Deterioration in an Air Oven
 - (xvi) ASTM D1149: Rubber Deterioration – Surface Ozone Cracking in a Chamber
 - (xvii) ASTM D2240: Rubber Property – Durometer Hardness
 - (xviii) ASTM E96: Water Vapor Transmission of Materials

- 2) American Association of State Highway and Transportation Officials (AASHTO)

- (i) AASHTO T 237: Testing Epoxy Resin Adhesive

B) Codes and Regulations of the Jurisdictional Authority

- 1) Work performed under this section shall be done in accordance all laws and regulations of applicable local, State, and Federal agencies.

C) Design Responsibilities

- 1) RockHardscp® manufacturer is responsible for design and selection of gaskets to provide a watertight tunnel lining for the specified design water pressure.
- 2) RockHardscp® manufacturer shall design and select lifting devices for the segments that will be compatible with the Contractor's proposed segment lifting, handling, and erection equipment.
- 3) It is the RockHardscp® manufacturer and Contractor's responsibility to design for all construction-imposed loads, including, but not limited to, the following:
 - (i) Loads across joint connections and along circumference, to maintain joint and installation performance.
 - (ii) Invert loads along longitudinal axis of tunnel derived from transport of equipment and materials.
 - (iii) Loads generated by grouting, handling, erection and the tunnel boring machine.

D) Design Criteria

- 1) Gaskets shall be designed for a minimum water pressure of 70 psi above atmospheric. Gaskets must provide for a watertight lining under all anticipated installation scenarios, including rotation at the segment joints of a least 1 degree. Design gasket and gasket groove for circumferential joint to provide full closure of gaskets with compression packing in place and prevent over-compression and damage to gaskets from thrust loads and loads across mechanical connections. Design gaskets and gasket grooves for longitudinal joints to provide full closure of gaskets with compression packing in place when the segments are in contact and to prevent over-compression and damage to gaskets from loads across mechanical connections.
- 2) Lifting devices must be designed to handle the segment weight, including dynamic and impact stresses induced during the lifting, transport, and placement of segments.

E) SCP Manufacturer Qualifications

- 1) Employ a qualified firm regularly engaged in the manufacture and fabrication of tunnel lining segments (with gaskets) of similar dimensions and tolerances to those specified, and who has provided precision tunnel segments for at least three large projects comparable to Work of this Contract in diameter, length, and type. Comparable work shall include mechanically joined, gasketed tunnel lining segments installed as permanent lining below the groundwater table. The SCP manufacturer shall have a minimum of 10 years experience in manufacturing of waste water applications in the U.S.
- 2) The gasket manufacturer shall have a minimum of 10 years experience and shall demonstrate that gaskets with the same profile have performed successfully in similar tunneling applications.
- 3) The polymer mortar manufacturer shall demonstrate at least 10 years experience in manufacture and distribution of the specified products.

F) Personnel Qualifications

- 1) All personnel engaged in manufacture of RockHardscp® segments shall be fully qualified and experienced in the manufacturing and installation of gaskets and mechanically connected precast segmented liner. Supervisory personnel at the segment plant shall have manufactured tunnel segments for at least three large projects comparable to Work of the Contract in diameter, length, and type. Comparable work shall include mechanically connected, gasketed tunnel lining segments installed as permanent lining below the groundwater table.
- 2) Polymer Mortar for Segment Repairs:
 - (i) Application of polymer mortar for segment repairs shall be by an applicator, approved in writing by the manufacturer of the materials supplied. The applicator shall demonstrate at least 10 years experience in the successful application of RockHardscp® repair mortars in tunnel or underground environments in 10 completed projects over the last 10 years.
 - (ii) The Contractor shall provide the services of a manufacturer's field representative to insure the proper application of the repair mortar system. The manufacturer's field representative shall have at least 10 years of experience as a product representative assisting contractors and/or supervising crews performing the RockHardscp® repair work. The manufacturer's representative shall be present to witness initial polymer mortar application and shall be available on an as-needed basis to provide consultation throughout construction.

G) Designer Qualifications

- 1) All calculations shall be signed and stamped by a professional engineer licensed in the _____.

H) Test Agency Qualifications

- 1) Employ a Testing Laboratory, accepted by a Construction Management Team (CMT) to provide specified inspection and testing, such as Element Materials Technology, 222 Cavalcade Street, Houston, Texas 77009, USA

III SUBMITTALS

A) Submit the following for approval in accordance with the Section indicated.

- 1) Construction schedules
 - (i) Manufacturing and delivery schedules for the SCP segmental lining
- 2) Shop drawings – Within 120 days after Notice to Proceed, submit the following:
 - (i) Shop drawings of each type of segment showing complete details of formwork, reinforcing, mechanical joint connection assemblies, joint relief, compression packings, gasket grooves, gaskets, grout holes and threaded lifting sockets, inserts, and accessories necessary for manufacture, storage transportation and erection. No segments shall be cast until shop drawings are reviewed and accepted.
 - (ii) Details and methods for marking segments with the required identifying information specified herein.
 - (iii) Data to demonstrate that the forms will provide the strength and rigidity required to maintain the dimensions and tolerances of the segments as specified herein and shown on the Contract Drawings.
 - (iv) Detailed design for segment lifting devices, grout holes and threaded lifting sockets including non-return grout valves, and reinforcing spacers and chairs. Allow for complete removal of lifting devices intruding into tunnel space.
 - (v) Details showing layout of facilities for casting, curing and storing segments
 - (vi) Detailed description of procedures for manufacturing, casting, curing, handling, transporting, storing, erecting and repairing segments, including calculations of stresses developed during handling, transporting, storing, erection, and jacking.

- (vii) Submit for acceptance by the CMT, an appropriate tolerance measurement system, for segment acceptance.
 - (viii) Submit a table for indicating the proposed procedures and materials to be utilized for repair of segments defects. Organize table based on the type and extent of damage. Also indicated proposed criteria for segment rejection.
 - (ix) Manufacturer's recommended instructions for preparing the surface and application of the polymer repair mortar. Submit narrative indicating the specific methods and equipment that the Contractor will use for preparation and application of the polymer mortar, including methods of chipping loose SCP, saw cutting, preparing exposed rebar, preparing polymer mix, physical application to segments, and cure procedures.
- 3) Product data – At least 120 days prior to the beginning of segment production, submit the following:
- (i) Material specifications for components of joint connection system and specifications describing pullout capacity, material properties of the assemblies, and methods to verify proper assembly during installation in tunnel
 - (ii) Gasket performance testing results including plotted curves of gasket deformation with increasing water pressure
 - (iii) Polymer Repair Mortar: Certificates of compliance with properties listed herein and single source manufacture for all compounds.
- 4) Samples and mock-ups
- (i) Submit samples of following
 - (a) Gasket – Five linear feet and one corner assembly.
 - (b) Gasket Adhesive – One pint each type used.
 - (c) Joint Connection Assemblies – Two of each set.
 - (d) Compression Packing – Three linear feet.
 - (e) Lifting/Grout Sockets including non-return valves – Provide two each of grout-hole insert with non-return valve and combination grout hole/lifting socket.
 - (f) Reinforcement Spacers – Three each.
 - (g) Polymer Mortar for Segment Repairs:

- (i) Contractor shall apply polymer repair compound on a sample area not less than ten square feet in size. When approved, the sample area shall serve as a project standard for all application of polymer mortar products specified herein.
- (ii) Demonstration RockHardscp® Liners
 - (a) Prior to segment production, prepare one full scale demonstration liner mock-up to demonstrate the accuracy and compatibility of the segments within the allowable tolerances. The mock-up shall consist of three complete RockHardscp® segmented rings erected vertically, without gaskets and packers, in a flat level base.
 - (i) Furnish to CMT, a 15-day written advance notice of start of assembly of demonstration liners.
 - (ii) Assemble entire demonstration liner rings at the Worksite or another approved location above ground, with longitudinal axis vertical to demonstrate the accuracy of segments within the allowable tolerances.
 - (iii) Furnish all tools and equipment to measure the required dimensions at no additional cost to the CMT.
 - (iv) If demonstration liners are not acceptable, dismantle liners as directed by the CMT, adjust forms, cast new segments if necessary, and erect (at no additional cost) new demonstration liners for acceptance. Discard all segments that are determined to be unacceptable.
 - (v) Begin full production of RockHardscp® segments only after obtaining written acceptance of the demonstration liners by the CMT.
 - (vi) Maintain demonstration liners intact for use as master rings in tolerance measurement until tolerances of completed rings are verified and the CMT authorizes removal of liners. Use dismantled segments for lining tunnel, if acceptable to CMT.
 - (b) A second full scale demonstration mock-up shall be erected at the place of manufacture of the TBM or at the construction site providing that the required certifications described in paragraph 1.03.A.9.a of this Section have been executed and accepted by the CMT. The purpose of the mock-up is to verify compatibility between the TBM and the segments.
 - (i) Furnish to CMT, a 15-day written advance notice of start of assembly of demonstration liners at TBM manufacturer's plant.

- (ii) Erect one complete ring, with the longitudinal axis horizontal, utilizing the erector arm of the TBM.
 - (iii) Provide supplemental framing and bracing as required to enable the erection of the lining.
 - (iv) Disassemble ring once the demonstration assembly is complete and the CMT is satisfied with the compatibility of the erector arm and the segments.
 - (v) Undamaged segments of the demonstration liner may be utilized for the tunnel lining.
 - (vi) Transport segments between the segment manufacturer's plant and TBM manufacturer's plant.
- 5) RockHardscp® Segment Manufacturer and Personnel qualifications
- (i) At time of bid, submit the names and qualifications of segment and gasket manufacturers, along with the following qualification information for each potential manufacturer: (If a joint venture is responding, provide the experience record of the firm or firms who will actually be responsible for manufacturing the RockHardscp® segments and providing quality control and responsible oversight for the manufacturing operation.)
 - (a) List of projects for which tunnel segments have been manufactured by candidate segment manufacturer in the last 10 years including:
 - (i) Title of the project
 - (ii) The owner, a representative of the owner and a current telephone number
 - (iii) The year(s) the work began and ended
 - (iv) Tunnel diameter and length
 - (v) Description of segments including number per ring, compressive strength, concrete mix details, and description of bolting type and arrangement.
 - (vi) Manufacturer of the segment forms.
 - (vii) Description of segment casting operation including location, facilities description and production rate for segments.
 - (viii) Description of gaskets including manufacturer product identification information, dimensions, design conditions (external pressure head, if known), and timing and details of gasket attachment.

- (ix) Quality control procedures and description of project experience record for quality and segment fit and performance when placed as tunnel lining.
 - (x) Description of working relationship with any partners involved in actual manufacture of the segments.
 - (xi) If any technical papers have been written describing the segment design details for any of the projects, provide reference information.
 - (xii) RockHardscp® segment manufacturer shall have a minimum of 10 years experience in the production, design and quality assurance of RockHardscp® structures.
- (b) Within 90 days after NTP, submit the names and segmental tunnel lining manufacturing experience of personnel responsible for overall segment casting operations and for those managing day-to-day casting operations and quality control at the RockHardscp® plant.
- (c) At least 45 days prior to the beginning of segment casting operations, submit the following information regarding qualifications of the polymer repair mortar manufacturer and applicator.
- (i) For the applicator, provide the following information regarding the projects successfully completed: project name, project location, owner (including name, address, and phone number of owner's representative with direct knowledge of the applicator's work), general contractor (including name, address, and current phone number of person with direct knowledge of applicator's work), date when work by the applicator was completed, and value of work performed by the applicator.
 - (ii) For the polymer mortar manufacturer's representative, provide qualifications including resume and number of years as a field representative for the manufacturer.
- 6) Warranties
- (i) Minimum of 100 year service life.
- 7) Installation and inspection data – At least 45 days prior to the beginning of segment casting operations, submit the following:
- (i) Segment repair and rejection criteria.
 - (ii) Submit details of a comprehensive quality control program to ensure compliance with the specifications. This program shall be described in detail in a quality control plan. Include dimensional monitoring in

accordance with the requirements of a Subsection 3.05.A.3 of this Section.

8) Performance reports and test data

- (i) Joint Connection Test Assemblies: Perform certified tests by a qualified independent laboratory to demonstrate the pullout capacity of the individual joint connector assemblies.
- (ii) These tests shall include the actual joint connector assemblies and shall be performed in the embedded condition using RockHardscp® of the design strength.
 - (a) Submit details and results of joint connection pull out capacity testing at least 60 days prior to the beginning of segment casting.
- (iii) During segment casting operations, submit methods and results of RockHardscp® testing as specified.
- (iv) Test method(s) and results to assess long-term performance of gasket materials.

9) Product certifications

- (i) Provide written certification from the RockHardscp® segment manufacturer of full and complete design coordination between the TBM manufacturer and the RockHardscp® segment manufacturer. Include a written certification by both manufacturers affirming the compatibility of the TBM and the liner system.

IV PRODUCT DELIVERY, STORAGE, AND HANDLING

- A) The Contractor shall provide and maintain an adequate supply of RockHardscp® segments of the required configurations at the site to ensure no interruption in ongoing tunneling progress due to lack of required support materials.
- B) Transport, store, and handle units to avoid damage and prevent excessive stresses from developing within segments. Follow all instructions from manufacturer of RockHardscp® segmental tunnel lining regarding transportation, storage, and handling of segments.
- C) Use supports or dunnage for storing and handling segments to avoid damage: do not subject segments to undue strains.
- D) Prevent damage to segment surfaces during handling and storage. Keep wire ropes, chains and hooks from direct contact with segment surfaces, joint assemblies, gaskets and joint compression packings.
- E) During cold weather, prevent water from filling the pockets and recesses of the segments and freezing.

- F) Provide the CMT a complete copy of all Bills of Lading.
- G) Ensure segments have attained the published strength prior to shipment.
- H) Inspect the segments, remove defective or damaged segments, and repair any minor damage, in accordance with specified procedures prior to loading segments.
- I) Shipped segments shall be in units of complete rings, all properly identified.
- J) Arrange deliveries to the site from either the plant or stockpile. Conform to the requirements of all the jurisdictional Authorities, rush hour restrictions, local bylaws, and site restrictions as specified.
- K) Polymer Repair Mortar Products:
 - 1) Deliver materials to the site in original packages or containers bearing the manufacturer's labels and identification.

PART 2 PRODUCTS

V RockHardscp® Definition & General Spec.

- A) Definition: RockHardscp® is the blending of thermosetting resins and mineral aggregates into a homogenous matrix that is cast into a mold or form, resulting in a cured, superior strength, corrosion resistant component such as tunnel segments, and other structures.
- B) General: This specification covers the materials, manufacture, installation, and testing of RockHardscp® tunnel segments for gravity sewer applications. RockHardscp® segments shall meet the requirements for continuous service in gravity sewer applications with a pH range of pH=1.0 to pH=10.0.
- C) Materials: RockHardscp® tunnel segments shall be manufactured using a matrix consisting of a vinyl ester thermosetting resin and mineral aggregates suitable for the intended application. The minimum resin content shall not be less than 8% by weight. The aggregates, which consist primarily of select mineral fillers, shall meet the requirements of ASTM C117 and ASTM C136, latest revisions, with the exception of the gradation requirements of both specifications. All select mineral fillers shall be clean of any organic materials, washed and dried and not contain any Portland cement or calcium carbonate. RockHardscp® matrix may incorporate recycled FRP reinforcing media. The RockHardscp® thermosetting resin shall not contain Volatile Organic Compounds (VOC's), Hazardous Air Pollutants (HAP's) or styrene. The resin shall be classified as a non-flammable, OSHA Class 3B having a minimum flash point of 90 degrees Centigrade. The resin shall have a minimum Heat Distortion Temperature (HDT) and Tg performance of 145 degrees Centigrade. The RockHardscp® matrix shall be

non-halogenated, non-brominated, non-electrically conductive and shall have a minimum Class A (1) Flamespread rating in accordance with ASTM E 162.

D) Chemical Resistance and Life Expectancy Test: The RockHardscp® tunnel segment manufactures shall be required to certify they have performed and completed the 3,000 hour, three-point-beam test as described below.

1) RockHardscp® test specimens shall be three beams tested in a flexural method as specified in ASTM C 580. The initial test samples represent a base line flexural strength value for the RockHardscp®. Three similarly sized beams shall be submerged in a stainless steel bath having a 20% sulfuric acid solution, with enough volume to cover up to ½” of the underside of the RockHardscp® beam depth. In a manner simulating ASTM C 580 flexural test, the beams shall be placed under a constant flexural load condition for a 3,000 hour exposure period. The load shall be equal to 60% of the average flexural strength of initial specimens tested to establish the base line flexural strength value for the RockHardscp®.

E) Physical Properties

1) The minimum physical requirements for the RockHardscp® material matrix shall be:

- (i) Minimum Compressive Strength 12,000psi
- (ii) Minimum Tensile Strength 1,500psi
- (iii) Modulus of Elasticity 2.1×10^6 psi
- (iv) Density 145 lbs/cf
- (v) Water Absorption 0.01%

F) Reinforcing Steel

1) Bars: ASTM A615, Grade 60, deformed bars as shown on the Contract Drawings.

2) Welded Wire Fabric: Welded wire fabric (WWF) of equivalent total tensile strength may be substituted for the bars shown on the Contract Drawings. WWF shall conform to ASTM A185, cold bent (no rebending), free of contamination or damage.

G) Spacers shall be compatible with the SCP matrix.

H) Gaskets, Neoprene 100%

1) Segments shall be supplied with water proofing gaskets on all mating faces. Gaskets shall be dense elastomeric synthetic rubber type, free of blisters, porosity, pittings, and other imperfections, manufactured as a continuous frame, with fully molded gasket corners mitered on each side, and vulcanized to provide uniform gasket thickness along entire length of mating surfaces.

2) Gaskets shall be designed for a water pressure range from atmospheric pressure to 70 psi above atmospheric pressure.

- 3) Test of Material Properties of fabricated processed gasket compound specimens to be performed ensuring gaskets meet the following minimum requirements.
- (i) Tensile Strength: ASTM D412, greater than 1300 psi
 - (ii) Elongation: ASTM D412, greater than 300 percent
 - (iii) Hardness: ASTM D2240, Durometer A; 65 +/- 5.
 - (iv) Compression Set: ASTM D395, Method B. Short-term: Less than 25 percent compression after 25 percent vertical compression at 70 degrees Centigrade for 22 hours. Long-term: Less than 15 percent compression after 25 percent vertical compression at room temperature for 72 hours.
 - (v) Ozone Resistance: ASTM D1149, by the method described in ASTM D518 Procedure A, with the following stipulation: No surface cracking of untensioned specimen (zero percent elongation) when immersed in a 200 parts per hundred million ozone solution for 100 hours at room temperature and 55 percent humidity.
 - (vi) Fire Rating: An RockHardscp® test rig shall be utilized to prove that the gaskets shall be installed in grooves in concrete blocks in a manner similar to the tunnel, with two opposing gasket profiles compressed to a joint gap of 1/8 inch. The RockHardscp® blocks shall duplicate the geometry of the segment joint surfaces. Via a burner, a minimum temperature of 800 degrees Celsius shall be generated at the intrados for a period of 30 minutes. The temperature generated during the test shall be measured at the gasket groove and it shall be demonstrated that less than ¾ of the gasket width is adversely affected.
 - (vii) Aging: ASTM D573, 70 hours at 100 degrees Centigrade. Limit changes in material properties as follows:
 - (a) Shore Hardness: Less than six units increase.
 - (b) Tensile Strength: Less than 15 percent decrease.
 - (c) Elongation: Less than 30 percent decrease.
 - (viii) Stress Relaxation
 - (a) For material sample tested at room temperature and 40 percent vertical deflection, with two minute measured stress set equal to 100 percent, do not exceed residual stress greater than 85 percent after 14 continuous days of testing.

- (b) Show by long-term tests, accelerated tests, or both, that after 100 years is greater than 60 percent of measured stress after 15 minutes at a 40 percent vertical deformation at room temperature.
- (c) Water Absorption – ASTM D471, 48 hours at 70 degrees Centigrade, maximum 10 percent increase by weight. Use distilled water for the standard test liquid.
- (d) Oil Absorption – ASTM D471, 70 hours at 70 degrees Centigrade, in IRM 903, maximum change in weight 110%

4) Performance

- (i) Gasket Groove Loads – Demonstrate through a combination of engineering analysis and laboratory experiments that gasket will not exert a load more than 3000 pounds per linear foot on gasket groove of RockHardscp® tunnel liner under any possible combination of manufacturing and installation tolerances that can exist.
- (ii) Groove Design – Gasket groove dimensions shown on the Contract Drawings are indicative only; the actual groove dimensions must be compatible with the selected gasket.
- (iii) Water tightness – Provide watertight seals even when complete closure of RockHardscp® tunnel liner segments is not possible because of manufacturing and/or installation tolerances. Prove by laboratory testing that at a T-shaped joint between two tunnel liner rings (three liner segments) gasket will resist, without leakage, a water pressure of 70 psi under a combination of gasket differential gap and gasket bearing surface offset conditions. Gasket differential gap is defined as difference between gasket vertical deflection at optimum gasket compression and actual gasket vertical deflection as tested. Gasket differential gap and bearing surface offset conditions for testing are as described below. Resist 70 psi of water pressure in the configurations for four continuous weeks without leakage.
 - (a) Along circumferential joint, a differential gap of 0.08 in (2 mm) on one side of the longitudinal joint, and a differential gap of 0.24 in. (6 mm) on the other side of the longitudinal joint.
 - (b) Along the longitudinal joint, a differential gap of 0.12 in., (3 mm), and a bearing surface offset of 0.40 in. (10 mm).
 - (c) Circumferential differential gap: 0.08 inch (2mm); and bearing surface offset of 0.40 inch (10 mm).
- (iv) Gasket material shall not suffer any adverse effects when exposed to groundwater at pressures up to 70 psi.

- 5) Experience of Gasket Suppliers – Demonstrate that tunnel liner gaskets have performed successfully in tunneling operations of similar applications.
 - 6) Gasket Adhesive – As recommended by gasket supplier to secure gasket to groove. Apply adhesive to groove in accordance with the gasket supplier's recommendations.
- I) Compression Packing – Bituminous fiberboard compression joint packers or other material approved by the CMT shall be provided to produce a maximum 1/8 inch joint gap thickness. The gaskets shall be designed to allow full closure of gaskets with compression packing in place. The compression packing shall extend no closer than ¼ inch from inside edge of gasket groove, no closer than 2 inches from corner of segments, and shall be the same width as the flat surface of the joint (less the ¼ inch clearance.)
- J) Mechanical Joint Connector
- 1) Minimum 7,000 pounds embedded pullout capacity yield on circumferential joint.
 - 2) Radial Joint Alignment Dowel, PPE
- K) Polymer Mortar for Segment Repair
- 1) Provide a two-component vinyl ester repair mortar for the repair of RockHardscp® exterior exposed surfaces conforming to the following:
 - (i) Suitable for use on vertical and overhead areas. The mortar is to be suitable for vertical applications having thicknesses greater than two inches.
 - (ii) The mortar shall be 100% solids. It shall be non-shrink to eliminate the possibility of shrinkage debonding over large areas, provide high structural compressive strength, provide high bond strength, provide a coefficient of thermal expansion similar to RockHardscp® and provide freeze-thaw resistance.
 - 2) Components: The vinyl ester mortar shall consist of factory proportioned two component system as supplied by SolidCast Polymer Technology (RockHardscp® Mortar) or Texas Polymer Products (TP-VE).
 - 3) Physical properties:
 - (i) Compressive Strength, 6,000 psi.
 - (ii) Tensile Strength, 1,000 psi.
 - (iii) Hardness, Shore D, 40 – 50.
 - (iv) Bond Strength, 1,000 psi.
- L) Welded Wire Fabric
- 1) Welded wire fabric per ASTM A185.

- 2) Welded wire fabric for use in deep patches shall be covered by a minimum of 2 inches of repair mortar to the neat line of existing (surrounding) concrete.

Part 3 EXECUTION

VI GENERAL MANUFACTURING REQUIREMENTS

- A) Produce RockHardscp® segments meeting the dimensional tolerances shown on the Contract Drawings as specified herein.
- B) Production Units: Continue production of the segments only after obtaining the CMT's written acceptance of the demonstration liners and successfully demonstrating the pullout capacity of the individual joint connector assemblies.
- C) Workmanship:
 - 1) Finished segments to be mechanically connected across joint faces. Provide joint connection assemblies to facilitate structural performance achieve and maintain maximum joint closedown, required gasket compression, and assist in ring stabilization and ring circularity.
 - 2) Provide gasket grooves and gaskets per CMT approved shop drawings. Design joint to prevent lip, which forms outside of edge of gasket groove, from contact with opposing lip during erection and thrusting of adjoining ring: prevent damage and spalling. Joint surfaces upon or against which gasket may bear must be smooth, free of spalls, fractures and imperfections that would adversely affect performance of joint. Verify that specified gasket groove load will not be exceeded.
 - 3) Provide compression packings on circumferential and longitudinal joint faces.
 - 4) Provide each segment with not less than one grout/lifting hole (with lifting insert) including non-return valves.
 - 5) Identification of segments:
 - (i) Provide a positive means of identifying each segment, acceptable to CMT, indicating the following information:
 - (a) Segment type designation
 - (b) Date of manufacture
 - (c) Mold number

- (ii) Markings such as logos, trademarks and proprietary information, except panel identification markings are prohibited on surfaces of tunnel liner segments.

6) Surface Finishes

- (i) Ensure that the maximum local irregularity on formed surfaces does not exceed a rounded protrusion of 1/64 in. above the general RockHardscp® surface.
- (ii) If the extrados surface is not formed, it shall be finished with a steel trowel such that the maximum local irregularity does not exceed a rounded protrusion 1/8 inch above the general RockHardscp® surface.

D) Formwork and Finishing

- 1) Fabricate steel forms with machined steel mating surfaces to conform to the dimensions and tolerances indicated, ensure segments of common design and cast in different molds are interchangeable. Joints are to be watertight and form surfaces shall be prepared to provide segments with finished surfaces free from irregularities.
- 2) Provide forms of special sizes and cross sections with metal thickness, reinforcement, stiffness and surface finish as required to form RockHardscp® surfaces smooth, free from irregularities, and conforming to required dimensions.
- 3) Construct molds for RockHardscp® precise segment with smooth casting faces such that a true, sound surface is formed.
- 4) Segments of common dimensions and cast in different molds shall be interchangeable.
- 5) Provide molds with individual identifications to ensure that all segments cast are marked and fully traceable.
- 6) Form mold joint surfaces to provide flat planes at the orientations shown on the Contract Documents.
- 7) Clearly identify loose mold components that affect the integrity of the mold as being part of the main mold.
- 8) Make all inserts to form mechanical connectors, holes, grout holes, etc., of approved steel or material having a coefficient of thermal expansion similar to that of RockHardscp®.
- 9) Provide steel templates, gauges, and testing apparatus, as required to enable the measurement of tolerances to ensure that each segment falls within two concentric volumes in space represented as the maximum and minimum dimensions allowed. Keep suitably protected from damage and distortion,

free from dirt and corrosion and ready for use in checking the segments as described hereinafter.

- 10) Securely anchor form inserts and embedded items to formwork.
- 11) Check each form prior to each production pour to ensure tolerances of each form are being maintained. Each form shall be rechecked after every production pour to ensure that no changes occurred in the form during casting (under vibration).
- 12) Keep a record of all the units cast in each form. Any form that becomes distorted or which casts faulty units shall be withdrawn from service until it is proved to the satisfaction of the CMT to be corrected.
- 13) Formed surfaces – Smooth form finish.
- 14) Back face – Segment shall be finished by a steel trowel. Provide a finish smooth and free from blemishes to ensure an adequate seal is achieved with tailskin seal of tunneling machine.

E) Segment Casting Preparation

- 1) The maximum variation in the position of the reinforcing bars shall be +3/8 inch – 0 inch. Except for internally at joint connectors, grout holes, and as otherwise shown, the minimum RockHardscp® cover over the reinforcement shall be 1-1/2 inches. Cages shall be sufficiently rigid to prevent deformation during manufacturing process.
- 2) Reinforcement shall be kept clean and dry and stored in such a manner that no distortion occurs.
- 3) Clean reinforcement of loose rust, mill scale, and other foreign material.
- 4) Fix RockHardscp® spacers so that the reinforcement is held firmly in the correct position within the formwork with all the cover specified. The spacers shall be rigidly fixed to the reinforcement to prevent displacement. If the spacers are wired on, the ends of the wires shall be turned into the unit.
- 5) Furnish spacers made from the approved RockHardscp® matrix for the segments, compacted and cured to the same standards as the segments, or from SCP of an equal or higher strength meeting the standards of this specification. Plastic spacers may be used.
- 6) Check reinforcement and other embedments within each mold.

F) Segment Casting

- 1) Produce segments under enclosed plant-controlled conditions with production areas protected against wind, rain, snow, dust, and direct sunlight.

- 2) The initial RockHardscp® placement temperature shall be no less than 50 degrees F.
 - 3) Consolidate and work RockHardscp® matrix into complete contact with forms and embedded items. Consolidate RockHardscp® matrix adjacent to side forms and along the entire length of forms to ensure a smooth surface finish after stripping of formwork.
 - 4) Gauge the first segment cast in any form to confirm that the segment conforms to the required dimensions and tolerances. Thereafter as a minimum, two percent of the segments cast on each shift, but not less than one segment per shift, shall be checked on a rotating form/mold basis to ensure that the dimensions and tolerances of the segments are maintained.
 - 5) All units of the same type shall be interchangeable and the dimensions for each unit shown on the Drawings shall be accurately reproduced within the tolerances indicated on the Drawings.
 - 6) At minimum frequency of one of every 1000 castings from each form, segments picked at random or by the CMT shall be built to form rings on the master rings to ensure that tolerances and interchangeability of segments are being maintained.
 - 7) If an out-of-tolerance segment is found, do not use that segment in the work or any other segments from the form found to be out-of-tolerance.
 - 8) Verify that the segments have attained the design strength prior to shipping by comparison with strength gain-maturity curves. Verify results with samples of RockHardscp®.
 - 9) The segments shall be delivered to the tunnel excavation sites in undamaged condition.
- G) Installation of gasket
- 1) Use gasket adhesive as recommended by gasket manufacturer.
 - 2) Place gasket into groove provided around segments, in accordance with manufacturer's recommendations.
 - 3) The gaskets shall be installed at the segment manufacturing plant prior to delivery to the project site.

VII FIELD QUALITY CONTROL

A) Field Acceptance Tests

- 1) Source Quality Control – Factory Tests

- (i) Provide a written notice at least 30 days before starting manufacture of segments, to allow CMT to inspect place of fabrication. Inspection by CMT will not relieve Contractor of responsibility of furnishing material and workmanship meeting specified quality requirements.
 - (ii) When directed by the CMT as a check on manufacture, assemble and connect randomly selected segments for at least two quality control rings, per 1,000 rings manufactured, to prove that outside surfaces of rings are coplanar and that tolerances of the completed rings meet specified requirements.
 - (iii) Provide the CMT sufficient office space, workers, and equipment for performing the inspections.
 - (iv) Provide equipment including master working templates, gauges and calipers adequate to determine accuracies and tolerances in manufacture.
- 2) Test RockHardscp® in accordance with testing procedure furnished in this document. See ASTM C579.
- 3) Conduct segment manufacturing dimensional quality control monitoring according to the approved method statement, submitted per the requirements of this Section. This shall include the following:
- (i) Number and frequency of measurements to be included for each production shift.
 - (ii) Include measurements of completed segment dimensions: positioning of all sleeves, lifting devices, gasket grooves, radial dimensions, thickness; positioning of reinforcing steel.
 - (iii) Indicate the tolerance acceptance criteria for deviations from specified dimensions. Provide a description for monitoring quality performance using upper and lower process control limits defined as the mean if each item measured plus or minus three standard deviations.

B) Tolerances

1) Dimensional Tolerances

- (i) Fabricate segments to dimensions and tolerances indicated on the Contract Drawings and as specified herein.
- (ii) Provide labor, equipment, templates, and facilities necessary for inspecting manufactured segments.

- (iii) Manufacture similar segments with such accuracy and uniformity in dimensions that they will be entirely interchangeable not only in individual rings but with segments of other rings

VIII ADJUSTMENTS AND REPAIR PROCEDURES

A) Repair of Segment Defects

- 1) Repair or replace structurally damaged and misaligned segments in accordance with the specifications to the satisfaction of the CMT; maintain structural integrity, durability and water-tightness of segmented lining system.
- 2) Segments that show excessive crazing, change or defects will be investigated by the CMT to determine the cause. Segregate and identify segments accepted for repair as to the class of defect(s). Mark and dispose of rejected segments immediately.
- 3) Major damage or irregularities to an RockHardscp® segment, which impair structural integrity or performance, will be cause for rejection of segment by CMT.

B) Inspection of RockHardscp® Segments

- 1) The CMT will have the right to inspect, check and reject finished segment not found to be in accordance with these specifications. To measure and determine accuracy of manufacture, provide and make available at all times, master templates and working templates, gauges, calipers and other equipment as may be required to inspect the segments.