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CITY ENGINEER

January 10, 2017

Wen-Tong Lin
Ohio Environmental Protection Agency
Division of Environmental and Financial Assistance
Lazarus Government Center
50 W. Town St., Suite 700
Columbus, OH 43216-1049

Re: Availability Waiver Request from American Iron and Steel (AIS) Requirements
Steel Fibers for Precast Concrete Tunnel Segmental Liner
Ohio Canal Interceptor Project

Dear Mr. Lin:

The City of Akron Ohio respectfully requests an availability waiver from the American Iron and Steel (AIS) requirements of the Clean Water Act, specific to steel fiber reinforcement for use in the precast concrete segmental tunnel liner for the Ohio Canal Interceptor Tunnel (OCIT) Project.

The OCIT Project is located in Akron, Ohio and includes approximately 6,200 lf of 27-foot inside diameter precast concrete segment lined tunnel, constructed utilizing a Tunnel Boring Machine (TBM). The tunnel lining is a one-pass system composed of steel fiber reinforced precast concrete tunnel liner segments, erected by the TBM as the tunnel excavation progresses. The OCIT project is being constructed to control combined sewer overflows and to meet EPA regulations.

The City included AIS requirements in the OCIT Project specifications under General Conditions, Article 15 **(Attachment 1)**. Paragraph 1.06A states in part: "The CONTRACTOR shall comply with all federal requirements applicable to the loan for the Project (including those imposed by the 2014 Appropriations Act and related SRF Policy Guidelines) which the CONTRACTOR understands includes, among other requirements, that all of the iron and steel products used in the Project are to be produced in the United States ("American Iron and Steel Requirement")..."

The City received correspondence from the OCIT project contractor, Kenny Obayashi/A Joint Venture (KOJV), via an email dated October 28, 2016 and a letter dated November 9, 2016 requesting relief from the AIS provisions for the steel fiber reinforcement incorporated into the precast concrete segmental tunnel liner for the OCIT project. KOJV's correspondence also forwarded letters from the precast concrete tunnel segment manufacturer, CSI Tunnel Systems-Forterra, JV (CSI), dated October 26, 2016 and November 4, 2016 indicating that there are no suppliers of domestic steel reinforcement fibers which meet the project specification requirements.

The information presented by KOJV and their precast segment manufacturer CSI is summarized as follows:

KOJV e-mail dated October 28, 2016, with attached letter from CSI dated October 26, 2016 **(Attachment 2)**

The KOJV e-mail included a response to an inquiry from the OCIT construction management team requesting information relative to the origin of proposed steel reinforcing fibers. This was included with a submittal from CSI for the precast concrete segmental tunnel liner. KOJV confirmed the non-domestic origin of the submitted reinforcing fibers and further noted that CSI would be requesting a waiver.

The CSI letter included with this e-mail stated that "...there are no available suppliers of domestic products that meet the required contract specification, meet our production requirements or that can demonstrate any experience in the use of high performance steel fiber reinforced concrete for precision precast concrete tunnel liners." CSI goes on to state that they have identified two suppliers of steel reinforcing fibers that meet the project specification and that both are non-domestic suppliers.

KOJV Letter No. OCIT-LTR-033 dated November 9, 2016
(Attachment 3)

This KOJV letter formally requests relief from the AIS provisions in regards to the steel fiber reinforcement for the precast concrete tunnel liner of the OCIT.

KOJV included the following points in their request for a waiver:

- No steel fibers produced in the United States are able to meet the OCIT project specification requirements.
- None of the domestic steel reinforcing fiber suppliers can demonstrate experience with their products in the production of precision high quality precast tunnel liners.
- Use of steel fiber reinforcing not meeting the OCIT project specification is not consistent with public interest. Excavation and lining of the tunnel are critical path activities and delays to the production of tunnel segments will negatively impact the project schedule and the ability to meet dates mandated in the consent decree and lead to increased costs.
- There is precedence for an AIS waiver for steel reinforcing fibers use in precast concrete segmental tunnel liners. The United States EPA, Office of Wastewater Management granted a waiver to the Northeast Ohio Regional Sewer District for the purchase of non-domestic steel fiber reinforcement to be used in the production of precast concrete segmental tunnel liner for the similar Dugway Storage Tunnel located in Cleveland, Ohio on July 15, 2015.

The KOJV letter has several attachments, including a letter from CSI to KOJV dated November 4, 2016. The CSI letter discusses the project's specification requirements for the steel fiber reinforcement and identifies requirements of the project specifications that are not met by domestic producers. CSI goes on to note that the project specified fibers have a proven performance history of project experience.

CSI also notes the use of domestic steel fiber reinforcing that does not meet the project specification, would increase cost, cause delays to project milestones, and necessitate the following:

- Change to the project liner design.
- Additional testing.
- Modifications of their proven manufacturing process of the tunnel segmental liners.
- Redesign of the concrete mix.

The KOJV letter includes steel fiber reinforcement product data for two non-domestic and for two domestic producers. The non-domestic steel fiber products meet the OCIT project specifications. However, review of the product data from the domestic producers indicates the inability of the domestic fiber products to meet the OCIT project specifications. Product data sheets are included for all products referenced in this section

The KOJV letter also includes a copy of the Dugway Storage Tunnel waiver approval and a copy of the OCIT Project Specification 31 74 16 Precast Concrete Tunnel Lining (Section 2.01.A.3 provides the steel fiber reinforcement requirements).

The City requested a memorandum from the designer for the tunnel and tunnel liner system, McMillen Jacobs Associates (MJA), addressing the steel fiber requirements for precast segmental tunnel liner segments. A memorandum, dated December 8, 2016, was received from MJA **(Attachment 4)** providing background information and justification pertaining to the OCIT specification for reinforcing steel fiber in the precast segmental tunnel liner.

A summary of the MJA memo of December 8, 2016 follows by section:

1.0 Background. MJA briefly discusses their design considerations, standard of practice, and references for design of steel fiber reinforced segmental tunnel liners.

1.1 Hooked End Fibers**.** MJA discusses the rational for hooked end fibers and provides a partial project listing of similar projects using similar hooked end fibers.

1.2 Evaluation of available fibers. MJA notes that performance and material requirements for steel fibers and steel fiber reinforced concrete were included in the project specifications.

MJA further notes that an inquiry was received during the bidding process from Fibercon (a US manufacturer of steel fibers) asking about a potential modification to the project specifications to allow their product to be considered in contractor bids. The response to the bidders was to bid as specified and that alternative fibers would be considered through contract mechanisms following contract award. No requests to consider alternative fibers were received after the initial inquiry.

2.0 Project requirements for steel fibers. In this section, MJA discusses the project specification for steel fiber to be used in the precast segmental tunnel liner. MJA notes that paragraph 2.01.A.3 of the Project Section 31 74 16 Precast Concrete Tunnel Lining **(Attachment 5)** of the contract documents defines acceptable steel fiber reinforcing as meeting three requirements:

1. Conforming to ASTM A820.
2. Fibers shall have hooked ends, a length of 2-3/8 inches and an aspect ratio of 80.
3. Do not use loose steel fibers that may cause balling during mixing.

Later subsections in the MJA memo provide the justification for the use of these OCIT contract specification requirements as summarized below:

1. Conformance to ASTM A820: MJA noted that ASTM A820 is the standard for steel fibers for use in concrete structures and that for precast concrete tunnel lining segments, an extensive record of successful case histories exists for steel reinforcing fibers conforming to ASTM A820.
2. Fiber Geometry: MJA noted that their design methodology combined recommendations from several technical papers specific to segmental tunnel linings with published standards for the design of steel fiber reinforced concrete structures. MJA researched and reviewed technical data for steel fibers and concluded that the specified fiber geometry was required to meet the conditions and demands on the tunnel liner for the OCIT project.
3. Fiber Distribution: MJA noted that a uniform distribution of steel fibers throughout the concrete element is critical to meet the demands of the liner system and that glued fibers are needed to prevent balling of the fibers.

Following initial discussions between the City, OEPA, and USEPA regarding a waiver request, a site visit was made by representatives from the City, the City's design engineer, and construction management team, OEPA, USEPA, and the project contractor to the CSI manufacturing facility located in Macedonia, OH. The site visit took place on December 13, 2016. The site visit included a discussion session followed by a tour of the CSI manufacturing facility during production of precast tunnel liner segments. During the discussion session, CSI offered information about testing that they performed on domestically made fibers. An email dated December 20, 2016 was received from KOJV forwarding a letter from CSI dated December 19, 2016 **(Attachment 6)** regarding testing CSI performed on the domestically made steel fibers including a narrative of testing and observations of the concrete mix with these fibers.

The CSI letter included attachments with the test results and various pictures, including side-by-side views of both the domestic and non-domestic fibers. The CSI letter notes that the domestic fibers do not meet the OCIT project specification, that the loose domestic fibers exhibited balling during the concrete batching process, and describes the negative impacts of the fiber balling behavior on quality and production of the tunnel segments. These domestically manufactured fibers failed to meet the project specifications for aspect ratio, hooked ends, and glued fibers.

In conclusion, the City believes it meets requirements to be granted an availability waiver to AIS requirements specific to the steel fiber reinforcement for precast concrete segmental tunnel liner for the OCIT project and is requesting an availability waiver be granted. Careful consideration was given to each aspect of the project's specification requirements for steel fiber reinforcing of tunnel liner segments. MJA, the tunnel and tunnel liner designer, determined during the design phase that steel fiber reinforcement meeting all of the specified criteria were required to meet industry standard of practice and the demands placed on the precast concrete segmental tunnel lining system. Efforts were made by the tunnel segment manufacturer to identify domestic sources capable of producing the OCIT project specified steel reinforcing fibers and none were found with the required capability to meet all specification requirements. The tunnel liner segment manufacturer tested domestically produced steel fibers that did not meet all of the project requirements and found the product was not able to consistently meet testing requirements and that these fibers exhibited balling in the concrete mix. CSI noted that the balling behavior results in non-uniform fiber distribution, which would have adverse effects on quality and production of tunnel segments.

Your assistance with timely approval of this waiver application is requested.

Respectfully submitted,

Mike D. Wytrzyszczewski
Engineering Projects Coordinator

MDW/mm

Attachments

c: J. Hewitt
M. DiFiore
D. Rendini (Parsons)
R. Frutchey (Thomarios)
G. Visca (DLZ)
P. Raleigh (MJA)
D. Chastka (KOJV)
File 2012-001-00

2017-01-10 oepa availability waiver - rev mw mm

NOTE: The following attachments were submitted with the waiver request and are available upon request by emailing SRF_AIS@epa.gov.

Attachment 2: KOJV email dated 10/28/16
Attachment 3: KOJV letter dated 11/9/16
Attachment 4: American Concrete Institute, ACI 544, 4R-88 (Reapproved 2009) Design Considerations for Steel Fiber Reinforcement. RILEM TC 162-TDF, Test and design methods for steel fibre reinforced concrete, Materials and Structures, Vol.33, 2003, pp75-81.
Attachment 5: General Conditions Article 15 WPCLF Contract Requirements
Attachment 6: CSI Tunnel Systems - FORTERRA, JV letter dated 12/19/16, Alternative steel fiber test results

Attachment 4

McMillen Jacobs Associate

Memo dated 12/08/2016

McMILLEN JACOBS ASSOCIATES

Memorandum

To:	Michelle DiFiore, City of Akron	Project:	Ohio Canal Interceptor Tunnel (OCIT), Akron, OH
From:	Christopher Caruso, MJA	cc:	Peter Raleigh, MJA
Date:	December 8, 2016	Job No.:	4560.0
Subject:	Design justification for specification of steel fibers for precast concrete tunnel liner segments		

1.0 Background

Development of the design and specifications for the OCIT segmental final lining took place between January 2013 and April 2015. In evaluating options for segmentation, concrete strength, fiber reinforcing, and segment thickness, proper adherence to industry standard of practice was a primary concern. Since there are no nationally recognized codes governing the design of segmentally lined tunnels in the US, the standard of practice is instead shaped by industry recommendations from overseas, local experience and experimental testing.

The references and standards used for design of the OCIT are comprised of established building codes for concrete design, special technical publications prepared by technical societies like the American Concrete Institute (ACI) and the International Union of Laboratories and Experts in Construction Materials, Systems, and Structures (RILEM), and heavily vetted technical papers written by experienced tunnel designers (for a list of the main design references used on the OCIT design, see section 3.0 of this memo). Additionally, members of the OCIT design team brought into the design their unique experiences working with these standards on prior segmental final lining designs.

1.1 Hooked End Fibers

Hooked-end fibers have an extensive history of successful use in segmentally lined tunnels due to their unique post-crack strengthening behavior. The degree of post-crack strengthening, determined by fiber shape and dosage, directly affects the axial and flexural capacity of the concrete, which in turn drives the choice of segment thickness and concrete strength. A balance must be struck between dosing fibers high enough to realize sufficient post-crack strength for an efficient structural design while avoiding fiber balling and clumping, which makes for poor fiber distribution and frequently occurs when fiber dosage is too high (for further discussion of fiber distribution, see sections 2.2 and 2.3). Hooked-end fibers have improved end anchorage when compared to straight fibers, allowing the concrete to carry higher loads at lower dosages. This behavior has been extensively studied and is reported in Chapter 2 of ACI 544.4R-88 (reapproved 2009) "Design Considerations for Steel Fiber Reinforced Concrete." Here, fibers with enhanced anchorage, including fibers with hooked ends, are identified as having enhanced post-crack strength and toughness when compared to straight-end fibers and unreinforced concrete, as proven by experimental testing.

Since the development of hooked-end fibers, designers of segmentally lined tunnels have come to regard them as a standard of practice because of the extensive production QAQC and experimental lab testing undertaken on the many jobs where they have been successfully used. A partial list of jobs where hooked-end fibers similar to those specified for OCIT were used is presented on in Table 1 on page 3.

1.2 Evaluation of available fibers

As the design evolved, steel fiber needs for the segmental tunnel lining design were continuously evaluated against many of the steel fibers that were available on the market. For further technical discussion of this process, see section 2.0. During final development of specification 31 74 16 "Precast Concrete Tunnel Lining," performance and material requirements for steel fibers and steel fiber reinforced concrete were included which reflected the structural needs of the segmental tunnel lining and standards of practice as previously discussed in section 1.1. Specifically, concrete performance requirements were included (see OCIT contract specification 31 74 16 para. 1.06), as is typical for segmental tunnel lining specifications to recognize that different Contractors would employ different means and methods of segment production and encourage competitive bids. Consideration of any alternative fibers proposed by a contractor that did not meet the material and dimensional requirements would therefore be given on a case-by-case basis.

During the OCIT project bidding period, one US manufacturer, Fibercon (Evans City, PA), queried the City of Akron about potential modification of specification 31 74 16 "Precast Concrete Tunnel Lining" to allow their product to be considered in Contractor bids. Specifically, the requirement for hooked-end fibers and aspect ratio of 80 was asked to be removed. MJA considered all the information submitted by Fibercon and evaluated this request for technical feasibility as soon as it was received (7/25/2015). The final response issued to bidding Contractors was that they should bid the job using fibers as specified and that any requests for alternative fibers would be considered through appropriate contract mechanisms following contract award. The technical basis for this decision was that Fibercon's request had not included sufficient testing data to prove that their fibers could be used in a conforming concrete mix that met all the performance requirements as defined in section 31 74 16 Para. 1.06.A.2.c. No further requests to consider alternative fibers have been received since that time.

Table 1: Partial List of Recent US Tunnel Projects Using Hooked End Fibers in Segmentally Lined Tunnels

	Location	Job	Years	Owner	I.D. (Ft)	Length (LF)
1*	Cleveland, OH	Dugway Storage Tunnel	2015-2016	Northeast Ohio Regional Sewer District (NEORSD)	26	14,750
2*	Washington D.C	First St. tunnel	2015	DC Water	20	2,750
3*	Los Angeles, CA	LA DWP Project AX-558-4	2013	LA Dept of Water and Power	10	2,960
4*	Cleveland, OH	Euclid Creek Tunnel	2011-2013	NEORSD	24	17,670
5*	Seattle, WA	Brightwater Conveyance System, BT3 Completion	2008-2011	King County	13	9,950
6*	Seattle, WA	Brightwater Conveyance System, BT4 West Contract	2008-2010	King County	13	21,100
7*	Seattle, WA	Brightwater Conveyance System, BT2 & BT3, Central Contract	2008-2010	King County	14.3	32,150
8*	Seattle, WA	Brightwater Conveyance System, BT1, East Contract	2007-2009	King County	16.5	14,050
9	Vancouver, BC	Port Mann Tunnel	2014-2015	Metro Vancouver	10.5	3,300
10	Vancouver, BC	Evergreen Rapid Transit Line	2014-2015	Translink	30	6,600
11	Washington D.C	Blue Plains Tunnel	2011-2013	DC Water	24	24,300
12	Washington D.C	Anacostia River Tunnel	2013-2015	DC Water	23	12,500

* Information courtesy of CSI Tunnel Systems

2.0 Project requirements for steel fibers

Paragraph 2.01.A.3 of Section 31 74 16 "Precast Concrete Tunnel Lining" of the contract documents defines acceptable steel fiber reinforcing as meeting three requirements:

1) Conforming to ASTM A820
2) Fibers shall have hooked ends, a length of 2-3/8 inches and an aspect ratio of 80
3) Do not use loose steel fibers that may cause balling during mixing

The technical reasons behind these three points will be presented in the following paragraphs.

2.1 ASTM A820

Steel fibers for use in concrete structures are standardized according to ASTM standard A820 "Standard Specification for Steel Fibers for Fiber-Reinforced Concrete." For precast concrete tunnel lining segments, an extensive record of successful case histories exists for fibers conforming to ASTM A820. Additionally, the design methodology used for segment design assumed the use of ASTM A820 fibers. Therefore, inclusion of this requirement in the project specifications was considered mandatory.

2.2 Fiber Geometry

The design methodology for the OCIT segments combined recommendations from several technical papers specific to segmental tunnel linings with published standards for the design of steel fiber reinforced concrete structures. These design references are cited in section 3.0.

Applying the recommendations of these references to OCIT project specific ground-interaction analysis, a minimum required post-crack residual flexural strength was determined for the tunnel segments. To ensure this minimum strength could be achieved by the Contractor, several different ASTM A820 steel fibers were researched. After reviewing the technical data supplied to us by the fiber manufacturers at the time of writing, it was determined that the required minimum strength for these segments could only be met by fibers having a minimum aspect ratio of 80, hooked ends, and a minimum length of 2 3/8". This finding was confirmed by further study of technical literature on tunnel segment design, which stated that acceptable levels of post-crack energy absorption (toughness) and residual flexural strength were most reliably observed in fibers with hooked ends (for further discussion of this requirement, see section 1.1) and aspect ratios over 60. Coupling these general recommendations with the specific demands of the OCIT project, including 27 ft tunnel internal diameter, mixed ground conditions, and conveyance of corrosive dry weather wastewater flows, it was determined that more stringent requirements were necessary to ensure the tunnel segment concrete could satisfy the demands of the project.

During design, it was also considered that a lower post-crack residual flexural strength may be acceptable if the tunnel segments are thickened. However, diminishing returns in reduction of required strength were found as thicker segments were considered due to the amplification of handling stresses, which govern the strength requirements for steel-fiber reinforced concrete tunnel segments. Additionally, thicker segments would require a larger TBM for the same 27ft internal diameter significantly impacting to the project cost for both segment concrete and additional muck disposal costs.

2.3 Fiber Distribution

In general, a uniform distribution of steel fibers throughout the concrete element is critical to achieving the post-crack residual flexural strengths and toughness values typically required for tunnel lining segments. The proprietary glue used to hold together the fiber "chips" i.e. multiple fibers glued together, dissolves as the concrete mixes and prevents "balling" (the formation of steel fiber clumps within wet concrete) a phenomenon often observed in concrete with poor fiber distribution. Since segments with poor fiber distribution would need to be rejected on this project, adding cost and delaying production, the prohibition on the use of loose fibers was specified to improve segment quality control. By eliminating the option for loose fibers, segment manufacturers would be afforded more flexibility in their production means and methods, and QC testing for fiber distribution, such as washout testing, could be done much less frequently.

3.0 References

1) American Concrete Institute (ACI), ACI 544.4R-88 (Reapproved 2009) Design considerations for Steel Fiber Reinforced Concrete, 2009

2) King, M.R. The Design and Use of Steel Fiber Reinforced Concrete Segments, Proceedings of Rapid Excavation and Tunneling Conference, Seattle, June 27-29, 2005.

3) RILEM TC 162-TDF, Test and design methods for steel fibre reinforced concrete, Materials and Structures, Vol. 33, 2003, pp75-81

Attachment 5

Specification 31 74 16

Precast Concrete Tunnel Lining

SECTION 31 74 16

PRECAST CONCRETE TUNNEL LINING

PART 1 - GENERAL

1.01 DESCRIPTION

A. This Section specifies requirements for the design, fabrication, and erection of bolted and doweled, gasketed, precast concrete segments as support for the tunnel boring machine (TBM) excavated tunnel and to serve as the final OCIT lining. Requirements for tunnel excavation by TBM and segment tail void grouting are specified elsewhere.

1.02 RELATED SECTIONS

A. Section 03 21 00, Reinforcement Bars

B. Section 03 30 00, Cast-in-Place Concrete

C. Section 31 09 00, Geotechnical Instrumentation and Monitoring

D. Section 31 71 19, Tunnel Excavation by Tunnel Boring Machine

E. Section 31 73 23, Tail Void Grouting

F. Section 31 74 13, Cast-in-Place Concrete Tunnel Lining

G. Section 31 79 10, Criteria for Work Under Railroads

1.03 REFERENCES

A. American Concrete Institute (ACI):
1. 347: Guide to Formwork for Concrete
2. 350: Code Requirements for Environmental Engineering Concrete Structures
3. 517.2R: Accelerated Curing of Concrete at Atmospheric Pressure - State of the Art
4. 533R: Guide for Precast Concrete Wall Panels

B. American Plywood Association (APA)

C. American Society for Testing and Materials (ASTM) International:
1. A325: Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength
2. A490: Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength
3. A615: Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
4. A820: Standard Specification for Steel Fibers for Fiber-Reinforced Concrete
5. A1064: Standard Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete
6. C39: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
7. C128: Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate
8. C1116: Specification for Fiber-Reinforced Concrete and Shotcrete

9. C1550: Standard Test Method for Flexural Toughness of Fiber Reinforced Concrete
10. C1609: Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)
11. D395: Standard Test Methods for Rubber Property – Compression Set
12. D412: Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers – Tension
13. D471: Standard Test Method for Rubber Property – Effect of Liquids
14. D573: Standard Test Method for Rubber – Deterioration in an Air Oven
15. D1149: Standard Test Methods for Rubber Deterioration – Cracking in an Ozone Controlled Environment
16. D2240: Standard Test Method for Rubber Property – Durometer Hardness
17. D6048: Standard Practice for Stress Relaxation Testing of Raw Rubber, Unvulcanized Rubber Components, and Thermoplastic Elastomers

1.04 DEFINITIONS

A. Precast Concrete Segments (Precast Tunnel Lining): Support system designed for specified construction and handling, ground and groundwater loads comprising bolted and doweled, gasketed, reinforced precast concrete segments erected as a ring within the TBM tail shield, that serves as the initial support and final lining, and against which the TBM thrusts in order to perform tunnel excavation.

B. Circumferential Joints: Joints between adjacent segment rings, perpendicular to the direction of the tunnel.

C. Leading Edge: The edge of the segment ring against which the TBM thrusts.

D. Radial Joints: Joints between adjacent segments within the same ring, parallel to the direction of the tunnel.

E. Lost Ground: As defined elsewhere.

F. Gap: Distance between segment edges at joints, dependent in part on the amount of gasket compression and packing thickness.

G. Gasket: Mechanical seal that is installed in a groove between two segments to prevent leakage between the two segments while under compression.

H. Packing: Load-distributing elements cut to the geometries of the radial or circumferential joints in which they are placed. The term “packing” does not mean “shimming” as used herein.

I. Proof Grouting: As defined elsewhere.

J. Tail Void Grouting: As defined elsewhere.

1.05 SUBMITTALS

A. Product Data:
   1. Manufacturer’s product data sheets, including recommendations and requirements for handling, storage, and protection. Provide:
      a. Three samples each of gaskets, gasket adhesive, packing, inserts, grout sockets, steel fibers, and each type of connection.
      b. Gasket information including test data demonstrating ability to meet specified performance criteria.
      c. Gasket lubricant.

B. Shop Drawings:
1. Shop drawings shall be stamped by a Professional Engineer licensed in the State of Ohio.
2. Fully dimensioned details of precast concrete segment geometries and features comprising:
   a. Layout and size of each segment.
   b. Number of segments per ring.
   c. Taper configuration.
   d. Key configuration.
   e. Concrete grade and type.
   f. Reinforcement.
   g. Joint configuration connection and details.
   h. Bolts, dowels, or other positively interlocking elements.
   i. Gaskets and gasket grooves.
   j. Packing, if used.
   k. Grout sockets/ports or grout port with combined lifting socket, if used.
   l. Segment identification information
   m. Shear pockets or lifting sockets.
3. Details for construction of each type of mold used to cast the precast concrete segments. Include for each type of segment:
   a. The number of molds to be fabricated.
   b. Details for securing embedded items in place during casting.
   c. Form release geometry.
   d. Mold tolerances.

C. Manufacture of Segments: No later than 90 days prior to the start of segment production, submit the following:,
1. Shop drawings providing physical description and properties of the precast concrete segment lining design, including details and dimensions for the manufacture, transportation, and erection of the segments. Include details of lifting segment points for transport into tunnel and erection.
2. Supporting design calculations demonstrating compliance with specified performance criteria, and complete information and details. Include calculations for the handling, stacking, transport, and installation load cases, joint design and reinforcement details for applied loads, and design of the gasket groove for the selected gasket. Include structural calculations specifying minimum compressive strengths when segments may be cured, stripped from molds, handled, stacked, transported, and erected. Calculations demonstrating the ability of the segments to handle design loads in conjunction with:
   a. Gasket line loads developed at the expected gaps. Integrate with other information including maximum accumulative packing limits for longitudinal and circumferential joints, where used, and line loads where no packing is used.
   b. The CONTRACTOR's means and methods to achieve the leakage criteria limits under the given hydrostatic and segment tail void and proof grouting pressures, adjusted by the factor of safety specified herein.
   c. Temporary construction loads, such as handling, transporting, and erecting and TBM jacking, with and without full benefit of segment tail void grouting, and other loads as may be applied during construction of the final precast tunnel lining.
3. All calculations shall be stamped by a Professional Engineer licensed in the State of Ohio, whose qualifications are as specified herein.
4. Details of segment production, comprising:
   a. Name, address, and contact information for the segment manufacturer.
   b. Location of casting and storage yards.
   c. Means and methods for:
      (1) Casting, curing, and demolding segments.
      (2) Affixing segment gaskets and packing, if used.

(3) Handling and storing segments.
(4) Measuring segments to show they meet the tolerances shown in the Contract Documents.

d. Segment production schedule.

5. Delivering, handling, storing, and protecting of segments, gaskets, and appurtenant items.

D. Working Drawings and Method Statements:

1. Erection method and details integrated with the requirements of Related Sections. Include calculations showing ability of the segments, both individually and as an erected ring, to handle TBM thrust loads.
2. Details that show integration of the segment lining with initial support and final lining at shafts, portals, and connection with the OCIT-2 Adit. Provide separate details, sequence drawings and calculations for temporarily supporting or removing segments as part of detailed break-in or break-out work sequences.
3. Details of segment repair and patching, comprising:
   a. Detailed procedure for process of repairing segments during fabrication and installation.
   b. Detailed procedure for repairing segments after temporary supports at OCIT-2 Adit and other connection locations as may be warranted based on CONTRACTOR's means and methods.

E. Quality Control:

1. Qualifications:
   a. Segment manufacturer.
   b. Segment designer.
   c. Test laboratory.
2. Certifications:
   a. Certificates of Compliance for materials specified in Part 2 herein.
   b. By segment manufacturer: that precast concrete segments meet minimum fabrication criteria specified.
   c. Separately, by segment designer and segment manufacturer: that precast concrete segments are capable of accommodating storage, transportation, handling, erection, TBM thrust, and grouting loads.
3. Quality Control Plans:
   a. Segment Fabrication:
      (1) Methods for measuring and assuring that specified tolerances are met with due consideration for thermal, moisture, and ambient temperature influences.
      (2) Methods for testing and sampling to verify minimum required compressive strength before stripping
      (3) Methods for controlling shrinkage and temperature cracking.
      (4) Record keeping and procedures for resolving quality defects.
      (5) Concrete mixes and batching. Include:
      (6) Methods for testing fiber reinforced concrete.
      (7) Methods for assuring a uniform distribution of fibers.
   b. Segment Protection: Methods for protecting segments and appurtenances from damage while handling, transporting, storing, installing, and maintaining during construction.
   c. Segment Ring Mockups: Measurements assuring compliance with specified and submitted tolerances and segment interchangeability requirements.
   d. Segment Delivery: Proposed casting, curing, and delivery schedule integrated with expected range of tunnel excavation advance rates.
   e. Segment Erection:
      (1) Methods for maintaining circularity and position of segment rings within specified limits.
      (2) Contingency plan addressing excessive deformation of segment

rings, including threshold values for deformation.

(3) Methods for assuring compliance with specified limits for leakage.

f. Segment Performance:

(1) Methods for maintaining circularity and position of segment rings within specified limits.

(2) Methods for measuring segment ring deformation and position.

(3) Methods for measuring water inflows both collectively and individually.

(4) Methods for demonstrating conformance of gasket material to specified design criteria.

g. Segment Remedial Work after erection:

(1) Proposed methods of repairs for damage within allowed parameters, or replacement.

(2) Proposed methods to:

(3) Correct misaligned segments and gaskets.

(4) Support and repair, or replace structurally damaged segments.

(5) Seal leaks to achieve specified leakage criteria limits.

(6) Revised work plan addressing fabrication, erection, and monitoring procedures if the Quality Control plans as specified herein are implemented on a recurring basis as determined by the CMT.

4. Recordkeeping:

a. Daily, no later than the end of the next shift, and integrated with TBM shift reports:

(1) Segment ring information:

(a) Sequentially numbered accounting of segment rings erected in the tunnel correlated to tunnel station.

(b) Segment type and ring orientation.

(c) Measurements of segment ring eccentricity with respect to the tail shield.

(d) Measurements of segment ring roll.

(e) Measurements of segment ring circularity.

(f) Notations of damage to segments, gasket, or appurtenances.

(2) Water flow measurements, including contributory flow from CONTRACTOR operations:

(a) At individual sources by station ahead of the trailing end of the trailing gear.

(b) Cumulative flow.

b. Within 30 days of completion of tunnel construction: As-built survey as specified herein.

5. Notifications:

a. 15 days in advance of assembling demonstration segment rings.

b. Within 1 day of removing a segment casting mold from service for repair or replacement. Survey results to verify conformance of repaired or replacement mold to tolerance requirements. In cases of repair, additionally submit written report including the nature of the damage and the method of repair.

c. Immediately upon discovering precast segments, gaskets, or appurtenances that do not conform to the requirements of the CONTRACTOR's design and the minimum design requirements set forth herein.

1.06 SYSTEM DESCRIPTION

A. Design Criteria:

1. General:

a. The precast concrete segments provide support for the tunnel and provide a finished structure for conveying flows. The precast concrete segments:

(1) Provide initial support for ground, groundwater, and other

construction loads during tunnel construction.

(2) Account for CONTRACTOR-controlled variables such as Lost Ground.

(3) Serve as the tunnel final lining with a design life of 100 years.

b. The minimum design requirements for the bolted, gasketed, precast concrete segments are shown on the Contract Drawings and herein, and are based on loading conditions and other requirements specified herein:

(1) Minimum 28-day concrete compressive strength: 8,000 psi in accordance with ASTM C39, or as needed to accommodate TBM thrust forces, erection, handling, storage, transport, and loads from TBM back-up system, whichever is greater.

(2) Minimum concrete cover to steel reinforcement, if any: 2 inches.

(3) Minimum steel reinforcement for bar reinforcement alternative: 0.5% of the gross concrete area in circumferential and radial directions.

2. Design Requirements:

a. Segment:

(1) The segment design shall meet the minimum requirements shown on the Contract Drawings and specified herein.

(2) Base design on ACI 350. Do not increase allowable stresses for temporary loads, or reduce load factors to account for temporary structure design.

(3) Size segments to allow for their fabrication, handling, erection, and to withstand TBM jacking forces and other design, handling, and construction loads.

(4) Stagger joints so that radial joints do not align with radial joints in adjacent segment rings, forming cruciform joints.

(5) Design segment joints to accommodate a gasket groove of the width required to accommodate the required gasket with the minimum clearances between:

(a) The segment extrados and the outer edge of the gasket groove to prevent spalling of the concrete due to required gasket line loads.

(b) The joint packing if used, and the inside edge of the gasket groove to prevent damage to the gasket when the packing is compressed, all while maintaining:

i. The required minimum segment gap width.

ii. The required dimensions of the packing relative to the segment joint.

(6) Provide chamfers for tapered radial joints to reduce stress concentrations as necessary to comply with specified requirements.

b. Segment Taper: Utilize only tapered segments. Straight segments are not acceptable.

c. Segment Reinforcement and Design: Steel fibers shall be used for segment reinforcement. Fibers made of other materials are specifically prohibited. Additional reinforcement may be required for segment handling, transport, stacking and installation shall be based upon the Contractor's final segment design configuration, stamped by the Segment Designer as specified herein, and subject to CMT review and ~~approval~~acceptance.

(1) The minimum design requirements for steel fiber reinforced precast concrete segments are shown on the Contract Drawings and specified herein, and are based on loading conditions and other requirements specified herein:

(a) Minimum concrete strength: as specified herein.

(b) Minimum required Toughness Performance Level (TPL) by Round Determined Panel Test: 4.

(c) Minimum required dosage of steel fiber: 50 lbs/CY.

- (d) Minimum flexural tensile strength at 28-days per ASTM C1609: 600 psi.
- (e) Minimum tensile strength by ASTM C496: 440psi.
- (f) Minimum post-crack equivalent residual flexural tensile strength at any deflection at or beyond the deflection of L/600 per ASTM C1609: 500 psi.

d. Gasket: Design gaskets for the design pressure and leakage criteria specified herein and indicated. Coordinate packing thickness if any, with the gasket system design to assure specified performance.

- (1) Provide gaskets capable of handling the following, with consideration of the degree of allowable segment ring out of roundness.
  - (a) The 150 percent of the maximum segment tail void grouting pressure specified.
  - (b) Minimum 8 bar hydrostatic .
- (2) Coordinate design of the gasket system with the gasket properties and the gasket groove depth to achieve the required design and performance criteria over the range of anticipated gap widths, and at the allowable tolerances as they relate to gasket seating offset and segment ring out of roundness.
- (3) Fulfill specified requirements when subject to offsets and gaps commensurate with those permitted under maximum allowable erection tolerances.
- (4) Of such durability that residual contact pressure between the gasket surfaces is capable of resisting the maximum hydrostatic head and environmental conditions indicated in the GBR continuously for the design life of the OCIT tunnel.

e. Bolted and Dowelled Connections:

- (1) Design bolted, dowelled, or other positively interlocking mechanical joint connections between segment panels. Radial joints shall be connected by bolts only.
- (2) Provide a minimum of two connections at each joint face for each segment except at circumferential joints for key segments which may utilize a single connection if connection spacing does not allow two connections such as shown on Contract Drawings.
- (3) Size connections to maintain adjacent gaskets sufficiently compressed to perform in accordance with specified requirements.
- (4) Minimum dimensions of contact between segment joints:
  - (a) 50 percent of the segment thickness along the short dimension of the radial joint.
  - (b) 90 percent of the segment length along the long dimension of the radial joint.
  - (c) 90 percent of the circumferential distance along the circumferential joint.
- (5) Design joints to allow sufficient closure of the gaskets to assure sealing against design pressures with compression packing in place. The packing shall distribute compressive stresses across the segment joint without affecting the ability of the segment gasket to withstand existing hydrostatic pressures, grout pressures, and jacking pressures.

f. Shimming: Prohibited.

g. Grout sockets:

- (1) Provide a minimum of one grout socket per segment for contact grouting purposes.
- (2) Equip with a threaded sleeve and cap.
- (3) Design to withstand maximum hydrostatic and grouting pressures as specified.

B. Performance Requirements:

1. Tolerances:
   a. Fabrication:
      (1) Segment geometry tolerance: As indicated
      (2) Cast with such accuracy and uniformity of dimensions that segment panels of the same type are interchangeable from segment ring to segment ring.
   b. Erection
      (1) Circularity tolerance: Limit the inside diameter measured across any internal diameter to ±0.50 percent of the theoretical diameter.
      (2) Variation between adjacent segment joint surfaces: The lesser of 7/16-inch and the tolerance established by the maximum allowable amount of gasket offset.
      (3) Limit ring roll to the following maximum absolute values:
         (a) Relative ring roll between adjacent rings: 1/8-inch.
         (b) Total ring roll: 2-inches.
      (4) Such that propulsion shoes from TBM do not cross radial joints
   c. Line and Grade:
      (1) Maintain tunnel profile within 3 inches of theoretical grade without ponding. Return to theoretical grade at no more than 1 inch every 20 feet, or as needed to eliminate ponding.
      (2) Maintain tunnel alignment within 12 inches of theoretical horizontal alignment. Return to theoretical alignment at no more than 1 inch every 20 feet
2. Tunnel Leakage Criteria:
   a. After segment tail void grouting:
      (1) Cumulative: 3 gpm per 1000 feet of tunnel.
      (2) For any ~~five~~100-foot length of tunnel: 0.~~02~~4 gpm.

C. Options:
1. Grout Sockets: One guide block out per segment may be used in lieu of a cast grout socket. Grout sockets may be combined with threaded lifting insert.
2. Packing: At the option of the CONTRACTOR subject to the following:
   a. Marine-grade plywood conforming to APA requirements. Maximum thickness: 1/8-inch.
   b. Maintain ½-inch clearance from gaskets under compression and segment edges.
   c. Compatible and coordinated with gasket design while under compression.
   d. If not used, demonstration by stamped calculation that chipping/spalling of segments during installation will not occur.

1.07 ASSURANCE

A. Qualifications:
1. Segment Manufacturer: Required to have provided bolted, gasketed precast concrete tunnel segments for two projects comparable to the work of this Contract in size and type within the last seven years.
2. Segment Designer: Civil Engineer currently registered in the State of Ohio with a minimum of 7 years of recent design experience in underground construction and in the design of bolted, gasketed, precast concrete segments in similar ground conditions and size to the work of this Contract.
3. Test Laboratory: Independent materials testing laboratory with a minimum of 5-year experience testing the materials of the type and for the purpose specified herein.

B. Acceptance Criteria:
1. No segments with visible damage or cracks shall be accepted inside the tunnel for installation.
2. Casting of segments to:

a. Individual panel and collective ring tolerances specified on accepted CONTRACTOR shop drawings.
b. Meet or exceed design requirements as specified, and verified and expanded by accepted CONTRACTOR-responsible design criteria.
3. Erection of segments to:
a. Meet or exceed specified leakage criteria.
b. Tolerances specified and indicated.

C. Preconstruction Meeting:
1. Schedule and conduct a prefabrication conference with the CMT and the Segment Manufacturer within 30 days of the intended start of fabrication of the segments. Discuss issues such as record keeping, tests, inspection logistics, quality control plan, and other fabrication-related matters.
2. Schedule and conduct a pre-installation conference with the CMT within 30 days of the intended start of tunnel excavation. Discuss issues such as mock-ups of the segment rings and other installation-related issues.

1.08 SITE CONDITIONS

A. Refer to and comply with requirements as specified.

1.09 SEQUENCING AND SCHEDULING

A. Ensure that segment production is adequate for tunnel excavation rates.

1.10 PRODUCT DELIVERY, STORAGE AND HANDLING

A. Transport the required amounts of segment panels in complete ring assemblies and as required to maintain a sufficient number of segment rings available to the tunneling operation.

B. Protect gaskets from direct exposure to sunlight and weather. Ensure protection of grout/lifting socket by keeping the sealed cap on at all times. Replace gaskets and joint packing that have shown signs of deterioration.

C. Transport, store, and handle segments, avoiding damage to surfaces, edges and corners, and avoiding the development of stresses exceeding the capacity of the segment.

PART 2 - PRODUCTS

2.01 MATERIALS

A. Reinforcing Steel:
1. Welded wire fabric conforming to ASTM A1064.
2. Bar reinforcement conforming to ASTM A615.
3. Steel fiber reinforcement:
a. Conforming to ASTM A820.
b. Fibers shall have hooked ends, a length of 2-3/8 inches and an aspect ratio of 80.
c. Do not use loose steel fibers that may cause balling during mixing.

B. Mechanical Joint Connector Systems:
1. Minimum sizes are indicated; select actual sizes to meet specified design and performance requirements.
2. Structural bolts, nuts and washers: ASTM A325 or ASTM A490.
3. Plastic dowels for circumferential joints:
a. Fiber reinforced engineered thermoplastic.
b. Ring formed pliable elastic surfaces.

c. Dowel size and load capacity to meet design criteria specified herein.

4. Acceptable manufacturers: Bolted and doweled connections: Sofrasar, Division BTP, or Accepted Equal.

C. Concrete: As specified for concrete where water may fall more than four feet onto the concrete surface.

D. Gaskets:
1. Dense elastomeric synthetic rubber.
2. Continuous over joint surfaces and of uniform gasket thickness along the entire length of mating surfaces.
3. Free of imperfections including: voids, blisters, inclusions, flow marks, porosity, and pitting.
4. Vulcanized corners mitered on each side.
5. Adhesive and its application as recommended by the gasket manufacturer.
6. Acceptable manufacturers: Datwyler Rubber and Plastics, www.rubber-plastic.ch, Phoenix Dichtungstechnik GmbH, www.phoenix-dt.de, or Accepted Equal

E. Grout Sockets:
1. Size to assure placement of grout as needed.
2. Acceptable Manufacturers: Sofrasar, Division BTP, www.sofrasar.fr, or Accepted Equal.

F. Gasket and Packing Primers and Adhesives: As recommended by packing and gasket manufacturers.

G. Packing: As specified herein

1.11 2.02 SOURCE QUALITY CONTROL

A. Fabrication:
1. Utilize molds fabricated from steel in accordance with ACI 347.
2. Cast and cure segments in a controlled environment protected against rain, dust, and direct sunlight.
3. Cast segments with blockouts that indicate where the segment may be drilled or cored such that segment bar reinforcement, if any, is not cut or damaged.
4. Provide hard steel trowel finish or similar to the extrados surface.
5. Steam cure segments and protect during storage in accordance with ACI 533R and ACI 517.2R for steam curing:
   a. After the segments are cast and have attained the required strength, place the segment forms in an enclosure or chamber large enough to allow complete circulation of steam.
   b. Do not release segment forms until the required stripping strength is attained, as determined by test cylinders.
   c. Enclosure or chamber ambient temperature shall not exceed 100 degree F for the first two hours of curing; maintain temperature between 90 degree F and 150 degree F until the required stripping strength is attained.
   d. Control cooling rate to limit temperature differential to avoid thermal cracking.
6. Segment Identification:
   a. Cast the segment type, taper, and mold identification directly on the segment intrados. Affix durable UPC bar code with the following information:
      (1) Serial number
      (2) Segment type
      (3) Mold number
      (4) Date/time of casting including cycle of shift
      (5) QC inspection record pre and post manufacture

(6) Cross referenced to associated concrete testing

b. Paint or cast the casting date adjacent to the above-cast information.

7. Segment alignment: Cast alignment indicators into the intrados of each segment to assist in their alignment.

B. Quality Control:

1. Mockup or Ring Fit-Up:

a. Prior to beginning production fabrication of the precast concrete segments, assemble and survey two rings of each different segment ring combination cast from proposed molds, and packing. Gaskets and mechanical connectors may be omitted except as needed to achieve ring geometry.

b. Utilize three sets of two segment rings:

(1) Assemble each set of rings separately at the place of manufacture by stacking segment rings one on top of another on a level, flat surface with joints staggered.

(2) Survey the rings to verify that the segments as cast meet specified fabrication tolerances.

(3) Adjust or replace forms as required to meet specified requirements.

c. The CMT will select the bottom ring from each of the sets to be retained as the master ring for the duration of segment casting operations to verify compliance with fabrication tolerances for the production segments using the same 2-ring configuration.

(1) Select segments for the upper trial ring in accordance with the following:

(a) Segments: Every 250th segment cast from each mold.

(b) Mold repair or replacement: First segment ring cast.

(2) Survey the segment rings to verify that the molds and segments meet specified fabrication tolerances.

(3) Adjust or replace forms as required to meet specified requirements.

2. Testing:

a. Gasket Physical Testing: Perform gasket tests of type required and recommended by gasket manufacturer to demonstrate compliance with design criteria specified herein. Perform such tests for a range of gasket offsets, as agreed between the CONTRACTOR and the CMT. Include the following:

(1) Water tightness tests.

(2) Reaction load tests.

(3) Gasket line load tests.

(4) Stress Relaxation

(a) Stress relaxation testing for gaskets shall be performed in accordance with ASTM D6048.

(b) Show by long-term tests that residual contact stress after 100 years is greater than 60 percent of measured stress after 15 minutes at a 40 percent vertical deformation at room temperature in accordance with ASTM D6048.

(5) Shrinkage – Logarithmic extrapolation to a 100-year life based on immersion of the gasket material in a hexane solution for 200 continuous days at room temperature in accordance with ASTM D471 – Indicate weight of gasket material specimen does not exceed 1.20 Wo or is less than 1.05 Wo, Where Wo is weight of material specimen before immersion in the hexane solution.

b. Gasket Material Tests: Material requirement tests shall be performed on specimens prepared from processed gasket compound to ensure that finished gaskets conform to the following minimum requirements:

(1) Tensile Strength – ASTM D412, greater than 1800 psi.

(2) Elongation – ASTM D412, greater than 300 percent.

(3) Hardness – ASTM D2240. Durometer A; 65+/5.

(4) Compression Set – ASTM D395, Method B.

(a) Short-term – Less than 12 percent compression after 25 percent compression at 70 C for 22 hours.
(b) Long-term – Less than 15 percent compression after 25 percent vertical compression after 72 hours at room temperature.

(5) Ozone Resistance – In accordance with ASTM D1149, Procedure A, with 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.
(6) Fire Rating – Self-extinguishing.
(7) Aging – ASTM D573, 70 hours at 100 C. Limit changes in material properties as follows:
   (a) Shore Hardness – Less than six units increase.
   (b) Tensile Strength – Less than ten percent decrease.
   (c) Elongation – Less than 15 percent decrease

c. The CONTRACTOR shall furnish to the CMT detailed notarized certifications for gasket conformance to the specifications, and the results of the tests performed

d. Perform testing for steel fiber reinforced concrete, as follows:
(1) Fiber testing by contractors lab witnessed by CMT
(2) Provide companion samples as directed by CMT for verification.
(3) Flexural strength testing:
   (a) In accordance with ASTM C1609.
   (b) Testing frequency during development of mix designs: Six beams for each mix.
(4) Steel fiber distribution testing:
   (a) For each sample, collect a minimum of 0.15 cubic feet of fiber reinforced concrete, with the sample taken directly from the mixer.
   (b) Weigh the samples in air and water similar to requirements of ASTM C128.
   (c) Wash out the steel fibers and collect using a magnetic device, or similar. Clean, dry and weigh fibers. Fiber volume shall be equal to the weight of fibers divided by the volume of the sample, in pounds per cubic yard.
   (d) Testing frequency:
      i. One set of three samples for each mix design.
      ii. One set of three samples per mixing unit per 24 hours during fabrication of segments.
   (e) Allowable tolerances for fibers:
      i. An average of 95% to 115% of the design fiber content from a set of three samples.
      ii. A minimum of 80% and a maximum of 130% of the design fiber content for each sample.
(5) Steel fiber quality testing:
   (a) Conform to the requirements of ASTM A820.
   (b) Testing frequency:
      i. Once during development of mix designs.
      ii. Once per month during fabrication of segments.

PART 3 - EXECUTION

3.01 GENERAL

A. Coordinate tunnel excavation and segment installation.

B. Use tapered rings as the exclusive means for negotiating curves and correcting horizontal and vertical misalignment.

C. Do not use packing of variable thickness, or more than one packing in a segment joint.

D. Except at the OCIT-2 Adit Connection, regardless of the type of segment positive interlocking mechanism, do not remove interlocking elements subsequent to their installation unless immediately replaced.

3.02 PREPARATION

A. Clean the segment erection area and prior erected segment surfaces to remove water, dirt, debris, and other foreign material prior to erecting each segment ring.

B. Examine segments for structural damage.

C. Lubricate segment gaskets prior to installation.

3.03 INSTALLATION

A. Grip and erect segments in a manner to accurately position and align segments and gaskets within specified tolerances.

B. Clean all faces of each segment and gasket prior to fitting adjacent segments.

C. Set segments to the required joint gap using the TBM segment erector.

D. Do not use the segment bolts or other positively interlocking elements to compress segment gaskets, but only to maintain segment gaskets in the compressed position.

E. Completely erect and fasten segments within the TBM tail shield before thrusting TBM forward.

F. Where the tunnel exceeds specified tolerances, perform remedial work in accordance with such submittal receiving acceptable disposition.

G. Perform tail void grouting as specified.

3.04 MAINTENANCE AND REPAIR OR REPLACEMENT

A. Repair or replace misaligned or structurally damaged segments to maintain tolerances, to maintain water-tightness, and to ensure stability and safety during construction.

B. Do not install segments, which exhibit any of the following:
1. Visible rebar, if used.
2. Cracks in excess of 0.008” (0.2mm) width or 12” length at any location or which affect design parameters.
3. Spalling in any amount affecting gasket or positively interlocking elements.
4. Spalling or cracking on the circumferential joint.

C. Replace segments which exhibit features that are grounds for rejection prior to their installation if the TBM has not advanced sufficiently to expose the first set of tail shield steel brushes in whole or part.

D. Repair segments exhibiting damage ahead of the trailing end of the trailing gear which exhibit any of the following:
1. Spalling to a depth in excess of 1-inch.

2. Chipping or flaking in excess of ½-inch measured in any direction.

E. Correct improper installation of any segment if the TBM has not advanced sufficiently to expose the first set of tail shield steel brushes in whole or part.

F. Modify construction methods to eliminate future reoccurrence and implement additional monitoring of the segment ring to assure compliance with specified leakage and tolerance requirements.

G. Perform regularly scheduled tasks to:
1. Clean the tunnel interior and invert of muck, grout, debris, and other foreign materials.
2. Maintain sumps, collection points, and pumps clear of trash and in good operating order.
3. Maintain clear passage for the flow of personnel, equipment and materials.

3.05 FIELD QUALITY CONTROL

A. Inspect precast concrete segments:
1. Before transporting and again before engaging the TBM segment erector.
2. Immediately after each shove of the TBM.
3. During and upon completion of segment tail void grouting.

B. Monitor the installation of each segment ring as related to the uniformity of the annulus between the segment ring extrados and the tail shield intrados. Record the distance between the tail shield intrados and the segment ring extrados using two sets of four longitudinal measurements along the transverse horizontal and vertical centerlines of the segment ring at the leading edge:
1. Take the first set of measurements upon erecting the segment ring, but prior to thrusting against the ring.
2. Take the last set of measurements upon completing the TBM shove, but prior to installing the next segment ring.
3. The CMT may elect to eliminate some or all of these measurements if it becomes evident to the CMT through visual or other means that the CONTRACTOR is consistently erecting the segment rings in accordance with other specified requirements.

C. Monitor the installation of each segment ring as related to the specified circularity tolerance in accordance with the requirements as specified herein.

D. Perform an as-built survey of installed segment rings for verifying the initial lining installation in accordance with specified tolerances:
1. Record measurements at the crown, invert, and springline, totaling four locations at every 5th segment ring
2. Maintain the survey no less than 1,500 feet and no greater than 3,000 feet behind completed segment backfill grouting operations.

END OF SECTION