

**TRACIE DAVIES**  
Director

THE CITY OF  
**COLUMBUS**  
ANDREW J. GINTHER, MAYOR

DEPARTMENT OF  
PUBLIC UTILITIES

September 26, 2016

Ryan Laake  
Project Engineer  
Ohio Environmental Protection Agency  
Division of Environmental and Financial Assistance (DEFA)  
Lazarus Government Center  
50 W. Town St., Suite 700  
P.O. BOX 1049 Columbus, OH 43216-1049

**Subject: Supplemental Information  
Public interest waiver request from American Iron and Steel provisions  
Clean Water State Revolving Loan Fund (CWSRF)  
Blacklick Creek Sanitary Interceptor Sewer, Section 6, Parts B&C (BCSIS)**

Dear Mr. Laake,

Technopref Industries, Inc., the manufacturer of precast concrete tunnel liner segments for the Blacklick Creek Sanitary Interceptor Sewer has proposed Type I steel fibers manufactured by Bekaert-Maccaferri as reinforcement. The fibers meet the requirements of the project Specification 03202 (attached). During the bidding phase for the project, no questions were received regarding the material requirements for the fibers to be used in the specified "hybrid" design containing both reinforcement steel and fibers. However after contract execution, it became necessary to modify the segment design to solely utilize fiber reinforcement as a result of the necessary equipment to fusion weld conventional reinforcement steel no longer being available in the United States.

Requiring a substitution for the Bekaert-Maccaferri fibers at this stage would result in significant delays to the project resulting from the need to purchase, ship, and commission new equipment specific to the new fibers, and to perform tests on the new segment design to provide quality assurance prior to segment production. These activities would delay the project by approximately 18 months, and the costs associated with this delay for contractor standby, concrete tunnel liner factory retooling and recommissioning, amongst other ancillary delay costs could be a minimum of \$4,500,000. This additional project cost is inconsistent with public interest, and as a result, the City of Columbus respectfully requests a waiver of the American Iron and Steel provisions to allow the use of the Bekaert-Maccaferri fibers.

Sincerely,



Nicholas Domenick, P.E.  
Project Manager  
City of Columbus, Division of Sewerage and Drainage



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Sewerage and Drainage | 1250 Fairwood Avenue | Columbus OH 43206 | Telephone (614) 645-7175 | Fax (614) 645-3801  
Water Administration | 910 Dublin Road Columbus OH | 43215 | Telephone (614) 645-7020 | Fax (614) 645-3993  
Director's Office | 910 Dublin Road | Columbus OH 43215 | Telephone (614) 645-6141 | Fax (614) 645-8019

columbus.gov

CC: Jason Sanson, P.E., Manager, Sewer system Engineering Section  
John Newsome, P.E., Administrator, Division of Sewerage and Drainage

Attachments: BCSIS Section 03202 – Steel Fiber Reinforced Concrete (Highlighted)  
BCSIS Addendum Document

This waiver request was submitted to the EPA by the state of Ohio. All supporting correspondence and/or documentation from contractors, suppliers or manufacturers included as a part of this waiver request was done so by the recipient to provide an appropriate level of detail and context for the submission. Some referenced attachments such as project diagrams, schedules, and supplier correspondence are in formats that do not meet the Federal accessibility requirements for publication on the Agency's website. Hence, these exhibits have been omitted from this waiver publication. They are available upon request by emailing [SRF\\_AIS@epa.gov](mailto:SRF_AIS@epa.gov).

September 7, 2016

Ryan Laake  
Project Engineer  
Ohio Environmental Protection Agency  
Division of Environmental and Financial Assistance (DEFA)  
Lazarus Government Center  
50 W. Town St., Suite 700  
P.O. BOX 1049 Columbus, OH 43216-1049

**Subject: Public interest waiver request from American Iron and Steel provisions  
Clean Water State Revolving Loan Fund (CWSRF)  
Blacklick Creek Sanitary Interceptor Sewer, Section 6, Parts B&C (BCSIS)**

Dear Mr. Laake:

The City of Columbus, Department of Public Utilities, Division of Sewerage and Drainage (the City), respectfully requests a variance from the American Iron and Steel Provisions (AIS) under the Clean Water State Revolving Fund (CWSRF) for the Blacklick Creek Sanitary Interceptor Sewer, Section 6, Parts B&C (BCSIS), as for reasons indicated within this letter.

The BCSIS project consists of 22,600 linear feet of 10-foot diameter finished concrete segment sewer constructed via tunnel boring machine, 400 linear feet of 10-foot finished diameter open cut sewer with a 120' section to be hand mined, and 4 in-line access shafts. Once constructed, the BCSIS will provide additional sanitary sewer capacity for a developing portion of the City's sewer collection system.

The City and our Construction Management Team for the BCSIS have received letters from the Contractor, Blacklick Constructors, LLC (BCL), on July 25, August 1, and August 10, 2016 regarding their inability to procure pre-cast reinforced concrete tunnel liner segments that comply with all provisions of AIS and the Contract Documents. The following is a summary of the information presented through BCL's letters:

BCL Letter No. 5 – July 25, 2016

BCL's bid included a precast concrete liner utilizing a hybrid reinforcement of fusion welded curved ladders and type I steel fiber structural reinforcing (as prescribed in the Specifications). The precast concrete tunnel liner would be produced by Technopref Industries, INC. (Technopref – concrete tunnel liner manufacturer).

The issues raised by BCL are as follows:



- BCL indicated that following further investigation, type I steel fibers that can reliably perform the requirements of the Specifications are not yet available from US based manufacturers. Consequently, BCL is requesting that the City file for an AIS variance.

In addition,

- The sole US supplier of fusion welded curved ladders (Engineered Wire Products) has declined to produce the curved ladders; and no other fabricators possess the specialty equipment necessary to produce the fusion welded curved ladders in the United States.
- A Canadian fabricator (Numesh) was identified as having the capability to produce the fusion welded curved ladders; however this would require an additional AIS variance to manufacture part of the concrete reinforcement outside of the United States. Additional costs would be incurred beyond BCL's original estimate.

BCL Letter No. 8 – August 1, 2016

- BCL indicated that discontinuing use of the fusion welded curved ladder reinforcing in favor of an all-fiber design would produce a structurally equivalent tunnel liner.
- Similarly to the fibers used in the hybrid design, the only steel fibers with abundant performance history are manufactured abroad by Bekaert-Maccaferri, which will require an AIS waiver.
- The all-steel-fiber reinforced segment utilizing Bekaert-Maccaferri fibers would not increase the cost of project.

BCL Letter No. 9 – August 10, 2016

- BCL restated their position that the steel reinforcement components of the concrete tunnel liner (and fusion welded curved ladder) as specified in the Contract Documents are not currently available in the United States and that both will require an AIS waiver. BCL stated that existing case law supports their position that if they incur additional costs or are delayed as a result of a change in the reinforcing type or being forced to wait until the specified materials are available, that they will be entitled to compensation and an extension in construction time.

Following receipt of these letters, we investigated BCL's position. Discussions were held with the segment manufacturer to substantiate BCL's statements. Additional market research was conducted in an attempt to identify additional curved reinforcement wire ladder fabricators. No additional equivalent suppliers beyond those previously identified by BCL or their suppliers were identified.

This additional market research also extended to domestic steel fiber manufacturers as we investigated the possibility of utilizing alternate types of domestically produced fibers (including Helix) for the structural reinforcing of the tunnel liner. Due to the lack of available performance data related to their use in concrete lined sewer tunnels, the use of alternative steel fibers is not possible at this time.

We believe that it is in the best interest of the Public to proceed with the proposed alternate all-fiber design utilizing a field proven type I structural fiber reinforcement for the reasons explained below:

### **Design**

BCL is finalizing several months of design efforts to propose an alternate structural reinforcement. The manufacturing of the precast concrete tunnel liner is planned to start on or before Dec 1<sup>st</sup> 2016. Extensive mix design testing has already been performed to prove the calculated performance requirements. Changing the design once more would inevitably set-back a critical path activity, the concrete liner production, by several months and would trigger a claim from the Contractor which would result in an increase of the project cost with no additional benefit to the Project.

### **Available track record**

Bekaert and Maccaferri fibers have been the tunnel industry standard and the structural reinforcement on numerous similar type tunnel projects, including in Ohio. Most of the precast concrete tunnel liner manufacturers have extensive experience handling this type of fiber (type I); and ample performance and longevity data is available on these fibers. Substituting this fiber for another would be equivalent to substituting predictability for uncharted performance, with limited durability and field performance data. As a result, this substitution could have serious consequences on longevity and ownership costs of this sewer infrastructure, as it could lead to additional maintenance costs, reduced service life, and possibly catastrophic loss of service, all of which are not in the Public's interest.

### **Manufacturer's production facility and experience**

Technopref has considerable experience manufacturing precision precast concrete tunnel liners including those using Type I steel fibers as structural reinforcement. It has as a result developed specialty equipment and specific batching procedures in order to surpass the specific technical challenges inherent to fiber reinforced concrete production (precision dosing of fibers, preventing the clumping or balling of fibers, uniform dispersion in concrete, cure time and temperature control, etc.).

These improvements and procedures took years of production to develop and refine, and they are intricately tied to the shape and size of the fibers used (type I specifically). Should another type of fiber be prescribed, the extent of the necessary modifications to the concrete liner factory would be substantial, both in time and in cost. Moreover, such a decision would most definitely result in loss of productivity, and possibly quality variability and unpredictability, and therefore, an increase in production costs and time. This would delay the overall Project, and result in claims for loss of productivity, increase in production costs, along with additional standby and extended overhead costs from both BCL and its supplier all at no additional benefit to the Project.

### **Field Quality and longevity**

As explained above, the use of Bekaert-Maccaferri Type I fibers have a substantial track record in precast tunnel liners, including sewers, and their consistent performance is proven. Every major aspect of the tunnel liner production and installation related to the use of this type of fiber is known and controlled, from liner production, curing, transport, handling in the tunnel, and finally

installation and TBM thrusting. During all these phases of its initial life, the liner is subject to abuses and unavoidable harms (cracking during curing, shipment, handling, installation and TBM thrust, radial or longitudinal misalignments and sub-optimal TBM thrust load transfers, circularity deformations such as egging, squatting or funneling of the rings further straining the ring radial and longitudinal connections, etc.).

Those deleterious effects were quantified and accounted for during the design of the liner only because of the existing information and because of previous experience with this type of fiber by Designers, Manufacturers and Contractors alike. If a new type of fiber was to be prescribed, the City and its rate payers would not be able to rely on these industry players' prior experiences and expertise, and would be forced to assume additional risks regarding the longevity of the liner and its service life.

### **Alternate rebar option**

In an effort to adhere to the intent of AIS, the CMT and Engineer of Record have examined the possibility of using traditional rebar cage reinforcement for the tunnel liner. Rebar cage reinforcing would result in a tunnel liner that has comparable performance and ensure compliance with all applicable provisions of AIS.

The results of the conceptual cost estimate found that rebar cage reinforcing would increase the manufacturing cost of the tunnel liner by approximately \$2,000,000. The time to manufacture rebar cage reinforced segments would be greater than any of the considered system. As the critical path for construction of BCSIS goes through tunneling operations, any additional time needed to manufacture the tunnel liner would ultimately further delay the project completion and result in additional delay costs.

The delay in procuring the alternative rebar cage reinforced segments, and the ultimate impact to the construction schedule and total construction time would justify a claim by BCL. The delay claim would be in addition to the \$2,000,000 cost increase to procure the rebar cage segments. At this time, it is anticipated that a delay in project schedule to substitute fibers for rebar cage reinforcement would range between two and five months. This would bring the cumulative costs in manufacturing changes and delay claims to approximately \$3,000,000 to \$4,500,000. Based on the bid price from BCL and their accompanying schedule of values, the original costs to procure the tunnel segments is \$14,500,000. The change in design would represent a 31% increase to the overall costs of the tunnel segments. The costs to cover such a claim on this project would go against the public interest. No additional value would be brought to the rate payers, and costs would contribute to increased sewerage rates and decrease overall public sewerage services provided by the City.

### **Prior Precedent**

In review of prior AIS variance precedent for the use of foreign reinforcing fibers for the construction of tunnel liner segments, a variance approval for Northeast Ohio Regional Sewer District's Dugway Storage Tunnel project was identified. For this project, an AIS variance was granted on the grounds that not permitting the use of foreign reinforcing fibers in the manufacturing of tunnel liner segments would be inconsistent with public interest.

Given that our proposed reinforcing system utilizing Bekaert-Maccaferri steel fibers is the same system as used for the NEORSD Dugway and Euclid Creek Tunnels, and failure to permit the use of these specific foreign steel fibers for BCSIS would also be inconsistent with public interest as explained above, the justifications for previously granting a variance to NEORSD are directly applicable to the BCSIS project.

In closing, a reasonable effort has been put forth in an attempt to meet all provisions of AIS. In accordance with section 608(c)(1) of the Clean Water Act, “[the requirements] shall not apply in any case or category of cases in which the Administrator of the Environmental Protection Agency...finds that – (1) applying [the requirements] would be inconsistent with the public interest.”

Given that every currently identified structural reinforcing solutions for the tunnel liner that would provide compliance with AIS would unavoidably burden the project with substantial cost increases, schedule delays, and claims from the Contractor, none of which would add additional enhancements or benefits to the Project, the City, or its rate payers, we hereby request a variance for the use of foreign Bekaert-Maccaferri steel reinforcing fibers for the BCSIS Project.

For the reasons identified above, we look forward to the timely approval of this waiver.

Sincerely,



Nicholas Domenick, P.E.  
Project Manager  
City of Columbus, Division of Sewerage and Drainage

CC: Jason Sanson, P.E., Manager, Sewer system Engineering Section  
John Newsome, P.E., Administrator, Division of Sewerage and Drainage

Attachments:

- Appendix A – AIS Submission Checklist and Instructions
- Appendix B – Contact Information
- Appendix C – BCL Letter 005, RFP 02 PCTSL Manufacturer Cost Increase
- Appendix D – BCL Letter 008, PCTSL Manufacturer Directive
- Appendix E – BCL Letter 009, PCTSL Production Cost Increase
- Appendix F – BCL BID AIS Signature
- Appendix G – BCSIS Section 02326, Precast Concrete Segmental Lining for Tunnel
- Appendix H – BCSIS Section 03202, Steel Fiber Reinforced Concrete
- Appendix I – BCSIS DP Bid Recommendation Letter
- Appendix J – BCSIS Schedule of Values
- Appendix K – Cost Comparison Rebar vs. Steel Fiber Segments
- Appendix L – NEORSD Dugway Storage Tunnel AIS Approved Variance

## APPENDIX C

BCL LETTER 005 – RFP02, PCTSL MANUFACTURER COST  
INCREASE AND ALTERNATE





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July 25, 2016

BCL Letter# CIP 650034-100006 - 005

Mr. Richard Houghton

BCSIS City Construction Manager  
Department of Public Utilities  
1250 Fairwood Ave.  
Columbus, OH 43206  
Subject: RFP 01 - Jefferson Township Bond Proposal

Re: Precast concrete tunnel segmental liner reinforcement – Production cost increase & alternate.

Gentlemen:

Pursuant to our discussion on July 19<sup>th</sup> and 21<sup>st</sup> concerning the concrete segment design, manufacture, and delivery, please review the following:

During the bidding process, Blacklick Constructors' precast concrete tunnel liner manufacturer: Technopref Industries, quoted the manufacture of the segments based upon the hybrid design shown in the contract drawings. Technopref located a fabricator of the required specialty wire products, Engineered Wire Products (EWP), who proposed to fabricate the specialty wire and wire mesh products (ex. curved ladders assembled through the fusion welding of curved and straight wire bars) essential for the assembly of steel cages required for each concrete segment. After the bid, EWP became aware that the cages could not be fabricated by them as required by the Contract's design. Technopref subsequently searched the US market for alternate specialty wire mesh fabricators that had the equipment required to manufacture curved wire mesh components to no avail. One alternate fabricator was identified in Canada (Numesh) that purports to be able to perform the required fabrication, but at a substantial increased cost to the project. If the City of Columbus requests that Blacklick Constructors pursue this manufacturing alternative, out-of-country fabrication will be required. Consequently, Technopref and Blacklick Constructors will expect additional compensation from the City.

Alternately, in an effort to save the additional expense to all, Blacklick Constructors has paid Hatch to redesign the segment reinforcing using 100% fiber supplied by the same manufacturer as in the hybrid design: Bekaert Maccaferri (BM). This redesign effort also considered alternate wire component configurations in an attempt to mitigate the specialty wire product supply issues to no avail. BM is the only manufacturer available that has the technical expertise and the experience in fiber reinforced precast concrete tunnel linings. All BM fibers are at this time only manufactured outside of the United States. Therefore an exemption would need to be obtained by the City which would allow buying steel outside the US (please note that this exemption would be required regardless of which design the City required BCL to pursue since both would use BM fibers). Preliminary test results using the proposed 100% fiber have been positive and its use would prevent added expenses and potential delays to the project.



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Consequently, Blacklick Constructors respectfully requests that the City approve the use of the Bekaert Maccaferri fibers and proceed with filing for the necessary exemption to the American Iron and Steel (AIS) requirements to facilitate the production of the segments. This decision has two benefits:

1. It saves the City the extra expense of outside the country manufacturing
2. It helps to maintain the scheduled delivery of the segments that must be coordinated with the start of tunneling.

Regards,

Ed Whitman, Project Manager

Blacklick Constructors LLC

## APPENDIX D

BCL LETTER 008 – PCTSL MANUFACTURER DIRECTIVE



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August 1, 2016

BCL Letter# CIP 650034-100006 - 008

Mr. Richard Houghton

BCSIS City Construction Manager  
Department of Public Utilities  
1250 Fairwood Ave.  
Columbus, OH 43206

Re: Precast concrete tunnel segmental liner reinforcement – Production cost increase & alternate.  
Ref: -CMS104.C  
-BCL Letter# CIP 650034-100006 - 005 PCTSL Manufacture cost increase & Alternate  
-Grout & Segment Reinforcement Meeting Discussion 7/19/16 @ SMOC Room 1044  
-Telephone conf. 7/28/16 Segment Designers' Reinforcement options  
-Email Receive 7/29/16@0808AM from City PCM re.: BCSIS Segment discussion 7/28/16

Gentlemen:

Pursuant to the discussions referenced above concerning the concrete segment manufacturing issues, Blacklick Constructors LLC (BCL) believes it needs to further clarify its position:

BCL has verified the hybrid (wire-mesh and fiber reinforcement) design provided in the Specifications as prescribed therein. The outcome of this verification has confirmed that while the original design is adequate, it is no longer attainable in the United States.

Technopref Industries, BCL's supplier of the precast segment lining, had secured Pre-Bid the supply of fusion-welded wire-ladders from a welded-wire fabricator in the United States that determined at a later date that they could not manufacture the required reinforcing components. During the time between the bid date and the award, this fabricator retracted its proposal forcing Technopref and BCL to seek a foreign fabricator that has an increase in manufacturing costs that is related to the supply, demand, transportation, and manufacturing equipment availability. BCL believes that this sudden and unexpected unavailability of critical and unique fusion welding equipment, and the apparent financial impact this will have on the manufacturing of an essential component of the tunnel, constitutes a changed condition.

BCL and Technopref have investigated and identified probable design alternatives that have the least impact, both in time and cost to the City; we have communicated these findings to the City in the above mentioned meetings.

However BCL and Technopref are unable to proceed further with the manufacture of precast concrete segments because of the following dilemma:

BCL could:

1. Proceed with manufacturing the ladders using a foreign fabricator which:
  - Is currently prohibited by the AIS requirements of the Contract, and Form I2-B. Project coverage.23 : ***“If the iron or steel is produced in the US, may other steps in the manufacturing process take place outside of the US, such as assembly? No. Production in the US of the iron or steel used in a listed product requires that all manufacturing processes must take place in the United States (...)”***
  - Will most definitely result in additional costs to the City.

Or:

2. BCL and Technopref can pursue the alternate design that uses exclusively steel fibers manufactured by Bekaert-Maccaferri as reinforcement:
  - Currently does not comply with the specifications,
  - Is expected to meet all the strength and reinforcing requirements of the prescribed design,
  - BCL and its suppliers have already incurred significant costs, both in re-design fees, and in extensive testing.
  - But, will not result in a cost increase or a claim to the City,

BCL is impartial to which solution the City wishes to proceed with, whether hybrid or full-fiber, as well as to the reasons for such choice; but, BCL is requesting an immediate and clear direction as to how the City wishes to proceed. Schedule delays may be unavoidable at this time, both due to deferrals in the choice and procurement of other segment components that are dependent on this decision, the delay to the start of production of the segments, and the rate of manufacturing limitations of the segment plant. All these will lead to a late delivery of segments and/or an extremely limited inventory which will delay the tunnel construction. The delay time involved cannot be determined at this time.

Regards,

Ed Whitman, Project Manager

Blacklick Constructors LLC

## APPENDIX E

BCL LETTER 009 – PCTSL PRODUCTION COST INCREASE AND  
ALTERNATIVE



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August 10, 2016

BCL Letter# CIP 650034-100006 - 009

Mr. Richard Houghton  
BCIS City Construction Manager  
Department of Public Utilities  
1250 Fairwood Avenue  
Columbus, OH 43206

Re: Precast concrete tunnel segmental liner reinforcement—Production cost increase & alternate.

Dear Mr. Houghton:

This correspondence shall serve as a supplement to Blacklick Constructors, LLC's (BCL) July 25, 2016 and August 1, 2016 letters regarding the previously described issues with the design and manufacture of the concrete segments and the ensuing delay caused by the same. This correspondence shall further represent BCL's final attempt to amicably resolve the aforementioned issue with The City of Columbus (the "City") prior to formally initiating the contractually required formal claims process.

The City's Specifications and Contract drawings call for the use of pre-cast concrete segments (a "product") with a hybrid (wire-mesh and fiber reinforcement) design. BCL preliminarily secured the supply of such product from Technopref Industries ("Technopref") prior to submitting its bid to the City. Technopref secured the supply of curved ladders, a critical component of the product, from a welded-wire fabricator based in the United States. As you are now aware, between the bid date and the award, the fabricator informed BCL that it would not be able to deliver the product. Technopref then diligently, but unsuccessfully, searched the U.S. market for an alternate fabricator to manufacture the hybrid design product. However, Technopref was able to find a Canadian-based fabricator who could manufacture the curved ladders. The retention of the Canadian fabricator would result in an increase in the costs related to the manufacturing, supply, and transportation of the required materials. Not only would the use of the Canadian fabricator increase BCL's costs, but it will also cause BCL to breach a provision of the contract with the City. The City's contract requires that all manufacturing processes take place in the U.S. Therefore, given that it has been impossible for BCL to obtain a critical component of the hybrid reinforcement in the U.S. and the use of the Canadian fabricator would breach a provision of the contract, it is impossible for BCL to currently perform under the existing terms of the contract.

In instances where it is impossible for a contractor to perform under the terms of the contract, a contractor may invoke the doctrine of impossibility of performance. "Impossibility of performance occurs where, after the contract is entered into, an unforeseen event arises rendering impossible the performance of one of the contracting parties." *Mth Real Estate, LLC v. Hotel Innovations, Inc.*, 2007 WL 2821135, at \*7 (Ohio Ct. App. 2007) (quotation and citation omitted). Ohio courts note that a party must show "that an unforeseeable event occurred, that the non-occurrence of the event was a basic assumption underlying the agreement, and that the event rendered performance impracticable." *Id.* at

\*8 (quotation omitted). Here, the City and BCL have already entered into a contract. An unforeseen event arose when BCL could no longer obtain the hybrid design product from a U.S. manufacturer. Furthermore, it is certainly true that BCL believed that it could perform in strict accordance with the contract requirements at the time that it entered the agreement with the City. Therefore, it is now legally impossible for BCL to perform under the terms of the contract.

One case in which Ohio courts previously encountered a similar set of circumstances is especially instructive in this instance. In *State ex. rel. Jewett v. Sayre*, a contractor entered into a contract with the county commissioners of Franklin County, Ohio, to furnish material and perform all work and labor necessary to build and complete a road. 109 N.E. 636 (Ohio 1914). The terms of the contract required the contractor to use local crushed sandstone of a certain quality and quantity. *Id.* at 639. After completing about two (2) miles of road, the contractor determined that it was impossible to obtain the necessary sandstone in the required quantity. *Id.* The contractor abandoned the contract and reached an agreement with the county commissioners for payment on the portion of the contract that the contractor completed. *Id.* at 639-40.

Unlike the contractor in *Jewett*, BCL is strongly committed to continue its contract and business relationship with the City and to deliver a successful project to the City. However, if the City wishes to proceed with the hybrid design, the City must be willing to make certain equitable adjustments and allowances for this changed condition. First, the City must amend the contract or allow a change order that directs BCL to obtain the hybrid design product through the Canadian-based fabricator. Second, the City must compensate BCL for the unexpected cost of obtaining this product from the Canadian-based manufacturer and all corresponding delays.

Please keep in mind that Ohio courts have repeatedly allowed a contractor to receive an equitable adjustment in instances where a contractor is required to use an alternate design that then increases the cost to the contractor. See *Oberer Constr. Co. v. Park Plaza, Inc. et al.*, 179 N.E.2d 168 (Ohio Ct. Common Pleas 1961). Ohio courts have also awarded an equitable adjustment when it has been impracticable, let alone impossible, for a contractor to perform the contract as originally contemplated. See *Tony Zumbo & Son Constr. Co. v. Ohio Dep't of Transp.*, 490 N.E.2d 621 (Ohio Ct. App. 1984). Many other courts have also allowed a contractor to receive an equitable adjustment when a changed condition has occurred, or there has been a change in the scope of the project. See *The City of Meridian v. Petra Inc.*, 299 P.3d 232 (Idaho 2013); *Design and Production, Inc. v. U.S.*, 18 Cl. Ct. 168 (1989). This principal is especially true when a cardinal change results from a proprietary specification as is arguably the case here.

It is mutually beneficial for the City and BCL to continue their relationship. As noted in our August 1, 2016, letter, schedule delays may be unavoidable at this time. However, if the City allows BCL to use the Canadian-based fabricator and equitably compensates BCL, it would save considerable long-term costs and allow BCL to deliver the project to the City as expeditiously as possible. BCL requests that the City issue a change order where BCL can purchase the products for the hybrid design from the Canadian-based fabricator and equitably compensate BCL for this unexpected expense along with the additional costs and time associated with this change.

Alternatively, the City may request that BCL investigate the design and use of a full fiber reinforced pre-cast concrete liner, which is expected to expedite the procurement process and mitigate some of the delays and extra costs associated with the impossibility for BCL to perform under the existing terms of the Contract. Although BCL had expressed in its letter dated August 1<sup>st</sup> that the full fiber solution would



1<sup>st</sup> that the full fiber solution would not result in BCL seeking additional compensation for cost and time, this statement applies only to the manufacturing of the tunnel segments, as of the date of writing. The absence of clear direction in writing from the City could compromise this statement, and will also preclude Technopref from developing the advance inventory it needs to sustain tunneling production, and consequently possibly delaying the Tunnel Boring Machine's (TBM) progress some time after the start of tunneling.

It is now imperative that the City make an expeditious and conclusive decision in accordance with its contractual obligations concerning the issues that BCL has formally brought to your attention in its July 25, 2016, August 1, 2016, and August 10, 2016 letters. We look forward to receiving your prompt response and working with you to accomplish an appropriate and equitable solution to this very difficult situation.

Regards,

Blacklick Constructors, LLC

A handwritten signature in blue ink, appearing to read "Ed Whitman", with a stylized flourish at the end.

Ed Whitman, Project Manager

cc: Richard D. Kalson, Esq. (via email)

# APPENDIX G

BCSIS SPECIFICATION 02326 – PRECAST CONCRETE SEGMENTAL  
LINING FOR TUNNEL

## SECTION 02326

### PRECAST CONCRETE SEGMENTAL LINING FOR TUNNEL

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**PART 1      GENERAL**

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**1.01      SUMMARY**

- A. This section includes the requirements for manufacturing, installing, erecting, and performing operations necessary or incidental to providing precast concrete bolted and gasketed segments for final liner rings in the tunnels, including necessary labor, materials, tools and equipment to obtain a watertight tunnel. The precast concrete segmental lining shall be capable of erection within the Tunnel Boring Machine (TBM) and of resisting ground and groundwater loads and loads imposed during manufacture, handling, transportation and installation.
- B. Concrete segments have been designed for anticipated environmental conditions, short- and long-term ground loads from ground characteristic described in the Geotechnical Base Report (GBR), external hydrostatic loads, and grouting pressures up to a maximum 30 psi above ambient hydrostatic pressure on the completed tunnel. Construction loads such as erection and thrust forces, up to 2,200 psi, have been assumed to be uniformly distributed over the available circumferential joint bearing surface area, exclusive of joint intersections and gasket. The design is detailed on the contract drawings.
- C. Contractor may propose segment design modifications for CMT approval in accordance with the requirements specified herein and in the GBR.
- D. The precast concrete segmental lining shall provide a 100-year service life. The minimum lining thickness shall be 9 inches, with minimum concrete clear cover over embedded reinforcing steel of 2 in. on the interior surface and 1<sup>1</sup>/<sub>4</sub> in. on the exterior surface of the segments.
- E. Check the segments for compatibility with the selected construction equipment, means, methods, and procedures including, but not limited to, handling, erecting, jacking, and grouting. Submit for review and approval any segment design modification required as a result of this check.

- F. Design the taper of the rings so that tapered rings can be used to maintain and provide changes in tunnel alignment. The use of straight (non-tapered) rings is acceptable in conjunction with tapered rings, provided that the specified gasket performance is maintained. The use of additional packers for alignment control is not permitted.
- G. Design, test and install gasket on each segment to provide watertight tunnel lining.
- H. Related Sections: include but not limited to
  - 1. Section 01300, Submittals
  - 2. Section 02950, General Tunneling Requirements
  - 3. Section 02965, Tunnel Boring Machine
  - 4. Section 02967, Ground Support and Protection
  - 5. Section 02990, Tunnel and Shaft Backfill Grouting
  - 6. Section 03200, Concrete Reinforcement
  - 7. Section 03202, Steel Fiber-Reinforced Concrete
  - 8. Section 03300, Cast-in-Place Concrete
  - 9. Section 03600, Grout

## 1.02 REFERENCES

- A. Reference Standards: The publications listed below form a part of this specification to the extent referenced. The publications are referred to in the text by basic designation only. Where a date is given for reference standards, that edition shall be used. Where no date is given for reference standards, the latest edition available on the date of Notice Inviting Bids shall be used.
  - 1. ACI 211.1, Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
  - 2. ACI 224.1, Control of Cracking in Concrete Structures
  - 3. ACI 301, Standard Specification for Structural Concrete
  - 4. ACI 305, Hot Weather Concreting

5. ACI 306, Cold Weather Concreting
6. ACI 309, Guide for Consolidation of Concrete
7. ACI 318, Building Code Requirements for Structural Concrete
8. ACI 350, Code Requirements for Environmental Engineering Concrete Structures
9. ASTM A36, Standard Specification for Carbon Structural Steel
10. ASTM A108, Specification for Steel Bars, Carbon, Cold Finished, Standard Quality
11. ASTM A123, Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
12. ASTM A153, Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware
13. ASTM A325, Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength
14. ASTM A563, Standard Specification for Carbon and Alloy Steel Nuts
15. ASTM C33, Standard Specification for Concrete Aggregates
16. ASTM C39, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
17. ASTM C157, Standard Test Method for Length Change of Hardened Hydraulic – Cement Mortar and Concrete
18. ASTM C469, Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression
19. ASTM C497, Standard Test Method for Concrete Pipe, Manhole Sections, or Tile
20. ASTM C719, Standard Test Method for Adhesion and Cohesion of Elastomeric Joint Sealants under Cyclic Movement (Hockman Cycle)

21. ASTM C920, Standard Specification for Elastomeric Joint Sealants
22. ASTM C1138, Standard Test Method for Abrasion Resistance of Concrete (Underwater Method)
23. ASTM C1202, Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
24. ASTM C1240, Standard Specification for Silica Fume Used in Cementitious Mixtures
25. ASTM C1582/1582M, Standard Specification for Admixtures to Inhibit Chloride-Induced Corrosion of Reinforcing Steel in Concrete
26. ASTM D395, Standard Test Methods for Rubber Property – Compression Set
27. ASTM D412, Standard Test Methods for Vulcanized Rubber and Thermo Plastic Elastometers Tension
28. ASTM D471, Standard Test Methods for Rubber Property – Effect of Liquids
29. ASTM D518, Standard Test Methods for Rubber Deterioration – Surface Cracking
30. ASTM D573, Standard Test Methods for Rubber Deterioration in Air Oven
31. ASTM D1149, Standard Test Methods for Rubber Deterioration – Surface Ozone Cracking in a Chamber
32. ASTM D2240, Standard Test Methods for Rubber Property – Durometer Hardness
33. ASTM F436, Standard Test Methods for Hardened Steel Washers
34. Precast Concrete Institute MNL 116, Manual for Quality Control for Plants and Production of Structural Concrete Products

1.03 DEFINITIONS (NOT USED)

1.04 SYSTEM DESCRIPTION (NOT USED)

1.05 SUBMITTALS

- A. Comply with the requirements of Section 01300.
- B. Submit within 60 days of NTP, the name of the segment and gasket manufacturers, names and experience of personnel managing the precast concrete batching plant, and a list of comparable tunnel projects and names and telephone numbers of clients where manufacturer's segments have been used successfully.
- C. Manufacture of Segments: Within 150 days of NTP, submit the following:
  - 1. Shop drawings of each type of segment showing complete details of formwork, dimensional tolerances, reinforcing, mechanical joint connection assemblies, joint relief's, gasket grooves, gaskets, inserts, and accessories necessary for the manufacture, transportation and erection of the segments.
  - 2. Structural design calculations, drawings, and description of construction methods to maintain and preserve the integrity, strength and rigidity of the formwork. Calculations and drawings shall be sealed by a Professional Engineer registered in the State of Ohio experienced in the design of formwork for precast tunnel linings.
  - 3. Structural analysis of tunnel segments to check all dynamic loads from construction means and methods. Analysis to be prepared by a Professional Engineer registered in the State of Ohio and experienced in the design of tunnel linings. Include the Professional Engineer's experience.
  - 4. Proposed segment design modifications, signed and sealed by a Professional Engineer registered in the State of Ohio and experienced in the design of tunnel linings. Submittal shall include calculations of stresses developed during handling, transporting, storing, erecting and jacking the segments. Include the Professional Engineer's experience.
  - 5. Design for removing and replacing segments if damaged during the first 12 inches of push.
  - 6. Detailed design for segment lifting device, reinforcing, spacers, and chairs. Design for loads across joint connections and along circumference to maintain joint and

installation performance, and invert loads along the longitudinal axis of the tunnel derived from transport of equipment and materials, and loads generated by grouting, handling, erection, shoving and any other loads generated by the TBM.

7. Minimum concrete strength which the segments must achieve to allow formwork removal.
8. Calculations of joint pull out (yield) and shear capacity of circumferential connectors and pull out (yield) on radial joint bolt assemblies due to erection and jacking forces.
9. Material specifications for components of joint connection system and specifications describing pullout capacity, material properties of the assemblies, and proposed testing procedures. Include details of gasket geometry, material specifications and methods to verify proper assembly during installation in tunnel. Include gasket manufacturer's quality control plan ensuring consistency of gasket material, dimensions, and configurations.

D. Repair Materials

1. Submit repair materials and procedures for segments with minor damage.

E. Quality Control Program Submittals: Within 180 days of NTP, submit the following:

1. Detailed description of procedures for manufacturing, casting, curing, handling, transporting, storing, erecting, and repairing segments. Include plans to control shrinkage and temperature cracking of segments.
2. Manufacturer's certification, including certified tests performed by a qualified independent laboratory, satisfactorily demonstrating the capacities of individual assemblies as follow:
  - a. Minimum 12,000 pounds pullout capacity on the circumferential dowel assemblies
  - b. Minimum 14,000 pounds shear capacity on the circumferential dowel assemblies



- c. Minimum 10,000 pounds pullout capacity on the radial joint bolt assemblies
  - 3. Test program prior to production of segments to establish curing process for 28 days specified strength
    - a. Test data including temperature gradient measurements from trial segments to verify that steam and/or other curing requirements can be achieved.
    - b. Data establishing the strength gain and curing time relationship at the raised temperature anticipated during the entire curing method process.
  - 4. Methods for testing to show that the curing process will result in uncracked segments with the strength required.
  - 5. Methods to verify that the design strength of segments as specified herein has been attained.
  - 6. Methods to verify concrete cure and strength results from cylinder tests performed in accordance with the requirements of Section 03300, Cast-in-Place Concrete.
  - 7. Methods for identification of each segment including segment type with match marks, date and shift cast, and serial number including mold identity.
  - 8. Methods for measuring required bolt tightness.
- F. Concrete Submittals: Not less than 60 days before commencement of trial ring production, submit the following:
- 1. Concrete mix design including ingredients and trial mixes signed by the mix designer and approved by the CMT. The mix designer shall have experience in designing concrete mixes for use in severe environments with use of corrosion inhibiting admixtures. Submit the mix designer's experience.
  - 2. Gradation of coarse and fine aggregates, and combined together. List grading and percent passing through each sieve size.
  - 3. Manufacturer's Certificate of Compliance:
    - a. Portland Cement

- b. Admixtures
- c. Aggregates
- d. Other ingredients including silica fume and/or fly ash

G. Samples: Provide samples of the following:

- 1. Gaskets: Five linear feet and one corner assembly
- 2. Adhesive: One pint of each type used
- 3. Joint Connector Assemblies: Two of each set
- 4. Compression Packing: Two feet
- 5. Reinforcement Spacers and Chairs: Three each
- 6. Radial and Circumferential Joint Connection Assemblies: One each

H. Other Requirements

- 1. Provide Manufacturer's product data
- 2. Provide notice of start of assembly of demonstration liners
- 3. Provide gasket performance test results
- 4. Provide segment repair methods and procedures for structurally damaged or misaligned segments
- 5. Provide details showing the layout of facilities for casting, curing, and storing segments

I. Submittals for Information

- 1. Daily Reports: consisting of segment rings erected in the tunnel correlated to tunnel station, measurements of segment ring eccentricity, roll and circularity, and location and amount of out-of-tolerance joints and build misalignment damage or defects.
- 2. Weekly Reports: consisting of measurement of segment ring deformation by location, as-built survey, fabrication and transport records, and repair logs.

3. Notifications on non-conformance during segment fabrication, mold repair and replacement, and assembling of demonstration segment rings as specified in 1.06.

## 1.06 QUALITY ASSURANCE

### A. Qualifications of Manufacturer

1. Employ qualified firm regularly engaged in the manufacture and fabrication of precast concrete tunnel lining segments of similar dimensions and tolerances to those specified, and who has provided precision tunnel rings in the last five years for at least three large public projects comparable to the work of this Contract in size and type.
2. Employ personnel fully qualified and experienced in the manufacture and installation of gaskets and mechanically connected precast segmental liners. Lead personnel shall have a minimum of five years experience on similar projects.

### B. Quality Control Program

1. Provide to the CMT for review a Quality Control Program for segment manufacture and fabrication. The manual shall be based upon PCI MNL 116.
2. Employ a testing laboratory, accepted by the CMT, to provide specified inspection and testing.

### C. Segment Dimensional Tolerances

1. Fabricate segments to dimensions and tolerances shown on the Drawings. Use tighter tolerances if necessary for erection and water-tightness.
2. Provide labor, equipment, templates, and facilities necessary for inspecting manufactured segments.
3. Submit for acceptance by the CMT an appropriate tolerance measurement system, for segment acceptance, to account and adjust for thermal, moisture, and ambient temperature influences.
4. Manufacture similar segments with such accuracy and uniformity in dimensions that they are entirely interchangeable not only in individual rings, but within segments of other rings.

5. As the initial test, erect and survey a set of two full rings of tunnel linings, including packing and connections, vertically on a flat level base to demonstrate the accuracy of segments within the allowable tolerances. The lowest ring shall be retained as a master ring for the duration of the Contract. The segments forming this ring may be selectively hand picked by the CMT. Ring fit-up tests shall be undertaken during production at a minimum frequency of one for every three hundred castings from each mold.
- D. Liner Ring Installation Tolerances: As shown on the Drawings and/or specified herein.
- E. Source Quality Control – Factory Tests
1. Provide written notice of commencement of production at least 30 days before starting production by the manufacturer of the segments to allow the CMT to inspect the place of fabrication. Inspection by the CMT does not relieve the Contractor of responsibility of furnishing material and workmanship meeting specified quality requirements.
  2. Allow the CMT access to work areas, and provide sufficient space, workers and equipment for performing the inspections.
  3. Provide equipment including master and working templates, gauges and calipers adequate to determine accuracy and tolerance in manufacture.
  4. Provide data to demonstrate that formwork design will provide rigidity and strength required to maintain manufactured and construction dimensions and tolerances specified.
  5. Based on the pull out capacity, as designed by the Contractor, to keep the circumferential joint closed after the TBM thrust jacks have been retracted and prior to the erection of the next ring, provide three certified tests each, by a qualified independent laboratory, satisfactorily demonstrating, in embedded condition, the following: minimum (yield) pullout and shear capacity on circumferential joint connector assemblies; pullout (yield) capacity on radial joint bolt assemblies based on erection forces as required by the Contractor. Include actual joint connector assemblies.

- F. Test Reports for Concrete: Submit the following test reports for each trial mix:
1. Admixtures: Test reports showing chemical ingredients and percentage of chloride in each admixture.
  2. Chloride Absorption: Determine chloride ion permeability in test samples of concrete mix in accordance with ASTM C1202.
  3. Statement from an independent testing laboratory identifying aggregate reactivity. Determine water-soluble chloride in each component of aggregates in accordance with ASTM C1218.
  4. Cylinder compressive test results.
  5. Drying shrinkage test data as determined in accordance with ASTM C157.
  6. Modulus of Elasticity (ASTM C469)
  7. Water Absorption (ASTM C497, Section 7, Method A)
  8. Abrasion-erosion loss (ASTM C1138)
- G. Other Test Reports: Submit the following test reports.
1. Joint pull out test
  2. Results of testing to establish curing process
  3. Gasket testing
  4. Concrete testing
- H. Markings: Provide segment identification markings on surfaces of tunnel liner segments and include date of casting.
- I. Acceptance: Segments with blisters, cracks or honeycombing are not acceptable. Segments not meeting the tolerances will be rejected. Damage to gasket grooves in excess of 5 percent of the length will also be a cause for rejection. Do not use rejected segments in the Work.

1.07 DELIVERY, STORAGE AND HANDLING

- A. Transport, store, and handle units to avoid damage and prevent excessive stresses developing within the segments
- B. Use supports for storing segments to avoid damage. Do not subject segments to undue strains.
- C. Prevent damage to segment during handling and storage. Keep wire ropes, chains, and hooks from direct contact with segment surfaces, joint assemblies, gaskets, and joint packings.
- D. Protect mating surfaces of segments and gaskets during transportation.
- E. Select combinations of straight and tapered segments to provide specified tunnel geometry, and for making alignment changes or corrections as necessary during construction.
- F. Store segments with joint compression packing and/or gaskets out-of-doors under conditions acceptable to the gasket manufacturer. Replace gaskets and joint packings that have materially deteriorated through exposure or have remained on segments for an extended period, as determined by the CMT.
- G. Inspect completed segments before loading. Discard defective and damaged segments. Do not use defective or damaged segments. Repair minor damage in accordance with procedures reviewed and accepted by the CMT.

|      |                                  |            |
|------|----------------------------------|------------|
| 1.08 | PROJECT/SITE CONDITIONS          | (NOT USED) |
| 1.09 | SEQUENCING                       | (NOT USED) |
| 1.10 | SCHEDULING                       | (NOT USED) |
| 1.11 | WARRANTY                         | (NOT USED) |
| 1.12 | SYSTEM STARTUP                   | (NOT USED) |
| 1.13 | INSTRUCTION OF OWNER'S PERSONNEL | (NOT USED) |
| 1.14 | COMMISSIONING                    | (NOT USED) |
| 1.15 | MAINTENANCE                      | (NOT USED) |

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**PART 2      PRODUCTS**

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**2.01      MATERIALS**

- A.      Concrete: Select and proportion ingredients using the trial batch method in accordance with ACI 211.1 to satisfy the following performance and durability criteria:
1.      Minimum compressive strength  $f'_c$  of 6,000 psi at 28 days. Use required average compressive strength,  $f'_{cr}$ , of lab-cured specimens as set forth in ACI 301 as the basis for selection of concrete proportions. When standard deviation data is not available,  $f'_{cr}$  must not be less than  $1.10 f'_c$  plus 700 psi.
  2.      Maximum water absorption of 9 percent when tested in accordance with ASTM C497, Section 7, Method A.
  3.      Maximum chloride ion permeability of less than 2,000 coulombs in concrete when tested in accordance with ASTM C1202.
  4.      Modulus of Elasticity of Concrete of not less than an average value of 4,400,000 psi when tested in accordance with ASTM C469.
  5.      Shrinkage at 28 days not greater than 0.048 percent when tested in accordance with ASTM C157. Range of values can vary from 80 percent to 120 percent of the average value in accordance with ACI 318.
  6.      Abrasion-erosion loss of 4 percent or less by mass in 72 hours when tested in accordance with ASTM C1138.
  7.      Resistance to severe sulfate exposure, as defined in ACI 318 Table 4.3.1.
  8.      Percentage Silica Fume: Shall be used between 5% and 7%.
  9.      One of the following corrosion reduction additives shall be used in the concrete mix at dosages recommended by the manufacturer:
    - a.      ConShield

- b. Xypex
  - c. Or approved Equal
- B. Concrete Constituents: Type II or Type V cement, aggregates, admixtures, and water as specified in Section 03300, Cast-In-Place Concrete and Section 03202, Steel Fiber-Reinforced Concrete. Cement shall have a maximum total of tricalcium silicate (C3S) and tricalcium aluminate (C3A) not to exceed 58%
- C. Admixtures: Admixtures, if used, shall conform to the manufacturer's recommendations. Admixtures shall not contain chloride or nitrates.
- D. Reinforcing Steel: As specified in Section 03200, Concrete Reinforcement.
- E. Steel Fibers: As specified in Section 03203, Steel Fiber-Reinforced Concrete.
- F. Molds
  1. Fabricate steel molds with machined steel mating surfaces to conform to the dimensions and tolerances indicated and provide segments with finished surfaces free from irregularities.
  2. Ensure segments of common dimensions and cast in different molds are interchangeable.
  3. Provide molds with individual identifications to ensure that all segments cast are marked and traceable.
  4. Form mold joint surfaces to provide flat planes. Joint planes shall lie perpendicular to the tangent or the surface of the segment at the joint, except at tapered or key segments.
  5. Clearly identify loose mold components that affect the integrity of the mold as being part of the main mold.
  6. Make all inserts to form bolt pockets, holes, grout holes, etc., of approved steel or material having a coefficient of thermal expansion similar to that of concrete.
  7. Provide molds with means to preheat the mold to a uniform temperature of at least 35 degrees F above the delivery temperature of the concrete.



8. Provide special sizes and cross sections with metal thickness, reinforcement, stiffness, and surface finish to form concrete surfaces smooth and free from irregularities, welding blemishes, and stain, and that conform to the required dimensions.
  9. Provide steel templates, gauges, and testing apparatus, as required, to enable the measurement of tolerances that ensure each segment falls within the maximum and minimum dimensions allowed. Keep protected from damage and distortion, free from dirt and corrosion, and ready for use in checking the segments as required.
- G. Mechanical Joint Connector System (Inserts, Anchors, Bolts and Accessories)
1. Ferrous Inserts and Anchors: ASTM A36 steel, hot-dip galvanized in accordance with ASTM A123 and ASTM A153
  2. Non-Ferrous Inserts: Polyamide plastic
  3. Bolts: ASTM A325, hot-dip galvanized
  4. Dowels: Push-in type, symmetrical and reversible
  5. Washers: ASTM F436, hot-dip galvanized
  6. Nuts: ASTM 563, hot-dip galvanized
- H. Gaskets
1. All segments shall be supplied with a waterproofing gasket on all faces. Gasket shall be similar to 86259 Mono EPDM Datwyler Rubber gasket or equivalent gasket from other manufacturer as approved by CMT.
  2. Supply segments with elastomeric waterproofing gaskets on all mating faces. Use gaskets that are dense Elastomeric synthetic rubber type, free of blisters, porosity, pitting, 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 the entire length of mating surfaces.
  3. Gaskets: Design for a minimum working water pressure of 58 psi above atmospheric.

Definition:

- working water pressure is the expected amount of static pressure on the structure
  - design water pressure (testing pressure) is double the working pressure for a safety factor of 2 which the gasket is selected, tested and supplied
4. Groove Design: Design gasket grooves for selected gaskets according to the gasket manufacturer's recommendations.
  5. The gasket must be design to be held fully compressed by the bolts or dowels in the lining. The load required in the bolts or dowels to ensure that the segment faces can be brought into contact shall be stated in the submittal. The Contractor shall confirm that the bolts and dowels proposed will provide the full compression force required.
  6. Test material properties of fabricated processed gasket compound specimens to ensure gaskets meet the following minimum requirements:
    - a. Tensile Strength: ASTM D412, greater than 1,400 psi.
    - b. Elongation: ASTM D412, greater than 300 percent.
    - c. Hardness: ASTM D2240, Durometer A; 65 plus or minus 5.
    - d. Compression Set: ASTM D395, Method B. Short Term – Less than 12 percent compression after 25 percent compression at 160 degree F for 22 hours. Long Term – Less than 25 percent compression after 50 percent vertical compression after 70 hours at 212 degree F.
    - e. Ozone Resistance: ASTM D1149, by method described in ASTM D518, 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.
  7. Gasket Performance

- a. Gasket Groove Loads: Demonstrate through a combination of engineering analysis and laboratory experiments that the gasket will not exert a load of more than 2,750 pounds per linear foot on the gasket groove of the concrete tunnel liner under any possible combination of manufacturing and installation tolerances that can exist.
- b. Water-tightness: Provide water-tight seals even when complete closure of tunnel liner segments is not possible because of manufacturing and installation tolerances. Prove by laboratory testing that the gasket at a T-shaped joint between two tunnel liner rings (three liner segments) will resist the test pressure under a combination of gasket differential gap and gasket bearing surface offset conditions for one week without leakage. Gasket differential gap is defined as the difference between gasket compression (in a direction normal to applied compressive load) at optimum gasket compression and actual gasket deflection as tested. Gasket differential gap and bearing surface offset conditions for testing are as described below:
  - c. Along the circumferential joint, a differential gap of 0.08 inches on one side of the radial joint, and a differential gap of 0.20 inches on the other side of the radial joint.
  - d. NOT USED.
  - e. Along the radial joint, a differential gap of 0.20 inches, and a bearing surface offset of 0.40 inches.
  - f. Along the circumferential joint, a differential gap of 0.20 inches, and a bearing surface offset of 0.40 inches.
- g. Prediction of Future Performance: Demonstrate by combination of engineering analysis and measured performance of gasket under the project conditions (maximum offset and gap), including any anticipated environmental deterioration, that the gasket is expected to perform its intended function over a design life of 100 years considering stress relaxation, aging, and shrinkage.

- h. Gasket material shall not suffer any adverse effects when exposed to groundwater at working pressures.
  - 8. Experience of Gasket Suppliers: Demonstrate that tunnel liner gaskets supplied have performed successfully for 5 years in tunneling operation of similar applications.
  - 9. Gasket Adhesive: As recommended by the gasket supplier to secure gasket to groove. Apply adhesive to groove in accordance with the gasket supplier's recommendations.
  - I. Compression Packing: Use bituminous fiberboard compression joint packers to maximum 1/8-inch joint gap thickness. Design joints to allow full closure of gaskets with compression packing in place. Extend the compression packing no closer than ¼ inch from inside edge of gasket groove and ensure it fills 90 percent of the joint gaps as well as fully compressing against abutting intersections.
  - J. Backfill Grout: Provide as specified in Section 02990, Tunnel and Shaft Backfill Grouting and Section 02965, Tunnel Boring Machine.
  - K. Guide Rod: Guide rod shall be made of plastic material with shear strength not less than 300 psi when sheared along diameter.
- |      |                        |            |
|------|------------------------|------------|
| 2.02 | EXISTING PRODUCTS      | (NOT USED) |
| 2.03 | MATERIALS              | (NOT USED) |
| 2.04 | MANUFACTURED UNITS     | (NOT USED) |
| 2.05 | EQUIPMENT              | (NOT USED) |
| 2.06 | COMPONENTS             | (NOT USED) |
| 2.07 | ACCESSORIES            | (NOT USED) |
| 2.08 | MIXES                  | (NOT USED) |
| 2.09 | FABRICATION            | (NOT USED) |
| 2.10 | FINISHES               | (NOT USED) |
| 2.11 | SOURCE QUALITY CONTROL | (NOT USED) |

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**PART 3 EXECUTION**

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|      |                       |            |
|------|-----------------------|------------|
| 3.01 | ACCEPTABLE INSTALLERS | (NOT USED) |
| 3.02 | EXAMINATION           | (NOT USED) |
| 3.03 | PREPARATION           | (NOT USED) |
| 3.04 | ERECTION              | (NOT USED) |
| 3.05 | INSTALLATION          | (NOT USED) |
| 3.06 | APPLICATION           | (NOT USED) |
| 3.07 | CONSTRUCTION          |            |

A. Workmanship

1. Provide joint connection assemblies to facilitate structural performance, achieve and maintain maximum joint close down, required gasket compression, ring circularity, and assist in ring stabilization. Furnish mechanical joint assembly system for radial joints and dowels for circumferential joints.
2. Provide gasket grooves and gaskets as approved by the CMT. Design joint to prevent lip, which forms the outside edge of gasket groove, from contact with opposing lip during erection and thrusting of adjoining ring. Prevent damage and spalling. Provide joint surfaces upon or against which gasket may bear that are smooth, free of spalls, fractures, and imperfections that would adversely affect performance of joint.
3. Provide compression packing on circumferential joint faces. Design circumferential joint to provide full closure of gaskets with compression packing in place, and to prevent over compression and damage to gaskets from thrust loads and loads across mechanical connections. Design radial joints to provide full closure of gaskets when segments are in contact. Stagger joints so that radial joints do not align with radial joints in adjacent segment rings.
4. Clean cast or drilled holes and recesses on the segment interior surfaces, then fill with non-shrink epoxy repair mortar. After segment installation, remove steel bolts,

washers, and nuts from segments within 200 feet upstream and 500 feet downstream of drop shafts prior to filling with mortar.

5. Identification of Segments

- a. Provide a positive means of identifying each segment, acceptable to the CMT, indicating the following information: Segment type designation; manufacturer's name or initials; date of manufacture; serial number (CMT to designate series); mold number.
- b. On tapered rings, indicate joint designation on inside face of liner segment and identify tapered side.

B. Surface Finishes

1. Ensure that the maximum local irregularity on formed and unformed surfaces does not exceed a rounded protrusion of 1/16 inch above the general concrete surface form.
2. Clean and coat forms with nonstaining release agent before each reuse.
3. Ensure smooth and clean segment surfaces for application of adhesive.
4. Accurately place reinforcing steel with tolerances in accordance with Section 03200, Concrete Reinforcement. Use cages sufficiently rigid to prevent deformation during manufacturing process.
5. Securely anchor form inserts and embedded items to formwork.
6. Check each form before and after production pour to ensure tolerances are maintained.
7. Formed Surfaces: Smooth form finish.
8. Back Face: Segment shall be finished by a wood float or steel trowel. Provide a finish smooth and free from blemishes to ensure an adequate seal is achieved with tailskin seal of tunneling machine.

C. Segment Preparation

1. Fix concrete spacers so that the reinforcement is held firmly in the correct position within the formwork with all the cover as specified. The spacers are rigidly fixed to the formwork to prevent displacement. If the spacers are wired on, the ends of the wires shall be turned into the unit.
2. Do not use spacers in the circumferential or radial joint regions. The joint regions are the areas up to a distance of 0.4 inches from the joint surface.
3. Make concrete spacers from the same concrete mix design and compacted and cured to the same standards as the segments. Any other spacers shall not be used.
4. Saturate all spacers with clean water prior to use. Spacers shall not be allowed to dry out after being fixed to reinforcement cages before concrete is cast.

D. Segment Casting

1. Produce segments under controlled plant conditions with production areas protected against rain, dust and direct sunlight.
2. Protect all concrete from hot and cold weather at all times during production.
3. Consolidate concrete into complete contact with forms and embedded items. Consolidate concrete 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. Thereafter as a minimum, gauge every fiftieth segment from each form. As a minimum, ensure that one segment from each form is checked weekly for dimensions and tolerances. When any variation in segment quality has occurred, increase the number of segments gauged to that required to re-establish the accuracy and consistency of production in accordance with the Contractor's Quality Control Procedure. If an out of tolerance segment is found, it shall not be used in the work, and any segments from a form found to be out of tolerance shall not be used.
5. 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 that the fault has been corrected.

6. All units of the same type shall be interchangeable and the dimensions for each unit shown on the Drawings are accurately reproduced within the tolerances indicated on the Drawings.
7. At a minimum frequency of one of every five hundred castings from each form, segments picked at random by the CMT shall be built to form rings on the maser rings to ensure that tolerances and interchangeability of segments are being maintained.
8. Verify formwork dimensions prior to each production casting to ensure tolerances of each form are being maintained.
9. Check reinforcement cages and other embedment's within each mold.
10. Perform tests to determine the in-place strength of concrete prior to lifting and to prove the attainment of strength.
11. Verify that the segments have attained the design strength prior to shipping through a combination of in-place strength testing and comparison with strength gain-maturity curves. Verify results with cylinder tests from concrete cured with segments.
12. The segments shall be delivered to the tunnel site in undamaged condition.

E. Curing

1. If steam curing is used, conform to ACI 517.
2. After demolding, as a minimum, cure in accordance with Section 03300, Cast-In-Place Concrete.
3. Removal of Segments from Forms: Do not attempt to remove segments from forms until compressive strength of 2,000 psi or strength as required for handling has been attained, as determined by ASTM C39. The CMT reserves the right to require increased compressive strength before allowing removal of segments from forms if there is evidence



of: distortion, cracking, spalling, or similar damage that could have been caused by insufficiently cured segments.

4. Test concrete in accordance with Section 03300, Cast-In-Place Concrete with the following additional requirements:
  - a. Mix Design and Curing Strength Test
    - i. Before start of manufacture, establish concrete mix as specified herein.
    - ii. Provide CMT with laboratory test results on the mix design 30 days prior to production.
    - iii. Any request to change the approved mix design shall be accompanied by laboratory test results and shall be submitted to the CMT at least 30 days before the mix is planned for use in production.
  - b. Production Test Cylinders
    - i. Prepare three cylinders and cure in accordance with ASTM C31 for each work shift or for every 100 cubic yards of concrete used, whichever is more frequent.
    - ii. Test cylinders shall comply with ASTM C39.
    - iii. At weekly intervals during segment manufacture, prepare two cylinders from the same concrete batch and cure in same manner as segments to demonstrate that minimum strength for form removal is being attained. If average strength of two cylinders is less than specified, cure related tunnel liner segments for a longer time, as reviewed and accepted and demonstrate minimum cured strength is met.

- F. Gasket Installation: Place gasket into groove provided around segments in accordance with gasket manufacturer's recommendations.

### 3.08 REPAIR/RESTORATION

- A. Repair or replace structurally damaged and misaligned segments in accordance with approved repair procedures and to the satisfaction of the CMT. Maintain the structural integrity, durability and watertightness of the segmented lining system.

- B. Prior to lining installation, repair minor damage to a concrete segment before erection in accordance with approved repair procedures. Prepare a table covering procedures for repair of segment defects. The table shall include a description of the type, extent of damage, and repair procedures in accordance with ACI 224R-90 and ACI 503.4-92, or basis for rejection of the segment.
- C. 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.
- D. Major damage or irregularities to the concrete segment which impair the structural integrity or performance will be cause for rejection.

3.09 RE-INSTALLATION (NOT USED)

3.10 FIELD QUALITY CONTROL

- A. Erection Tolerances:
  - 1. The diameter of the internal surface of all rings shall not deviate from the design diameter by more than 0.5 inch.
  - 2. Steps on the internal surface between abutting segments and the roll of one ring relative to the adjacent ring shall not be greater than 0.2 inch.
- B. Establish a program for measuring deformation of the tunnel lining system during installation as specified herein and in Section 02970, Monitoring Systems. Install four anchors or other approved surveying points at 90-degree spacing at every 25<sup>th</sup> segment ring for Tunnel Diameter Measuring Devices (TDMDs) readings. Measure deformations and compare to previously recorded measurements.
- C. Monitor the installation of each segment ring before and after shove as related to the specified erection tolerances. Inspect the conditions and the competence of lining daily and immediately after each shove of the TBM.
- D. Measure horizontal and vertical diameter on selected sets of rings on a daily basis during and upon completion of tail void grouting no less than 1,500 feet behind the tail shield, and submit the as-built survey within 72 hours of when the data is gathered. If

measurements indicate excessive deformations are occurring, advise the CMT immediately and take corrective measures. Deflection will be considered excessive if diameter changes by more than 0.5 inch from that measured at the time of completion of ring build are exceeded.

- E. The CMT has the right to inspect and reject finished segments not found to be in accordance with these Specifications. To measure and determine the 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.

|      |               |            |
|------|---------------|------------|
| 3.11 | ADJUSTING     | (NOT USED) |
| 3.14 | CLEANING      |            |
| 3.15 | DEMONSTRATION | (NOT USED) |
| 3.16 | PROTECTION    | (NOT USED) |
| 3.17 | SCHEDULES     | (NOT USED) |

+ + END OF SECTION + +

# APPENDIX H

BCSIS SPECIFICATION 03202 – STEEL FIBER REINFORCED  
CONCRETE

**SECTION 03202**  
**STEEL FIBER-REINFORCED CONCRETE**

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**PART 1      GENERAL**

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1.01 SUMMARY

- A. This Section includes:
1. This Section specifies requirements for steel fiber-reinforced concrete for use in the precast concrete segmental lining.
  2. Furnish all labor, equipment and incidentals required to provide concrete reinforcement as shown and specified.
- B. Related Sections: The Work of the following Sections is related to the Work of this Section. Other Sections, not referenced below, may also be related to the proper performance of this Work. It is the Contractor's responsibility for perform all the Work required by the Contract Documents.
1. Section 01300 - Submittals
  2. Section 02326 - Precast Concrete Segmental Lining for Tunnel
  3. Section 02950 - General Tunneling Requirements
  4. Section 02965 – Tunnel Boring Machine
  5. Section 02990 – Tunnel and Shaft Backfill Grouting
  6. Section 03100 – Concrete Formwork
  7. Section 03200 – Concrete Reinforcement
  8. Section 03300 - Cast-in-Place Concrete
  9. Section 03600 - Grout

## 1.02 REFERENCE STANDARDS

- A. The publications listed below form a part of this specification to the extent referenced. The publications are referred to in the text by basic designation only. Where a date is given for reference standards, that edition shall be used. Where no date is given for reference standards, the latest edition available on the date of Notice Inviting Bids shall be used.
- B. American Concrete Institute:
1. ACI 211.1 – Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete
  2. ACI 214 – Evaluation of Strength Test Results of Concrete
  3. ACI 301-10 – Specifications for Structural Concrete
  4. ACI 318-08 – Building Code Requirements for Structural Concrete and Commentary
  5. ACI 350-06 – Code Requirements for Environmental Engineering Concrete Structures and Commentary
  6. ACI 544 - Fiber-Reinforced Concrete
- C. American Society for Testing and Materials:
1. ASTM A820 - Standard Specification for Steel Fibers for Fiber Reinforced Concrete
  2. ASTM C39 - Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.
  3. ASTM C452 – Standard Test Method for Potential Expansion of PortlandCement Mortars Exposed to Sulfate
  4. ASTM C496 - Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens
  5. ASTM C1116 - Standard Specification for Fiber-Reinforced Concrete
  6. ASTM C1609 - Standard Test Method for Flexural Performance of FiberReinforced Concrete (Using Beam With Third Point loading).

### 1.03 DEFINITIONS

- A. Flexural Strength: first peak flexural strength of a beam in flexure as defined by ASTM C1609 and Part 3.
- B. Residual Flexural Strength  $f_{e3}$  (also called equivalent residual strength): residual strength of a beam in flexure as defined in Part 3 herein.
- C. Splitting Strength: splitting tensile strength as defined in ASTM C496 and Part 3.

### 1.04 QUALITY ASSURANCE

- A. Qualifications:
  - 1. The Contractor shall have or appoint a Precast Manufacturer that has at least (10) ten years of experience in the production of segments for reinforced precast concrete segmental lining, and experience on at least 2 projects with steel fiber reinforced segments.
  - 2. Provide a project superintendent who has five years of experience and worked on at least (3) three Steel Fiber Reinforced Reinforcement for Concrete contracts using similar equipment as required for this project.
- B. Testing:
  - 1. The Contractor shall provide test results that demonstrate compliance with the required testing and test results before the commencement of segment production.
  - 2. In addition to the testing specified in Section 03300, the following tests shall be undertaken:
    - a. ASTM C1609 - Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beams with Third Point Loading);
    - b. ASTM C496 - Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete specimens;
    - c. Fiber content tests as described in 3.04.B.
  - 3. ASTM C1609 Fiber Testing

- a. All equipment used shall comply with the requirements of ASTM C1609.
- b. Contractor or their Precast Manufacturer, shall retain the services of an AMRL accredited concrete test laboratory that is listed in the ASTM Lab Directory as a lab which performs test method ASTM C1609, meets the requirements of ASTM C1077 per CCRL Inspection, and has demonstrably tested a minimum of 500 beams in accordance with ASTM C1609 and/or ASTM C1018.
- c. Each laboratory technician working on this project shall be ACI certified.
  1. Laboratory shall establish, by testing, the dosage rate of the proposed fiber that is necessary to achieve the target residual flexural strength
    - a. The fiber dosage shall yield a target residual flexural strength value such that the fifth percentile of residual flexural strength, determined by any valid statistical means, is not less than 158psi
    - b. Until sufficient data have been generated, as determined by the CMT, the 5th percentile shall be defined as the mean minus 1.65 standard deviations.
    - c. The mean value derived from testing three beams from a single batch shall constitute one test.
    - d. The target mean strength shall be the average of the values derived from all tests of three beams, and the standard deviation shall be calculated by accepted statistical methods using the mean of each test, and multiplying the standard deviation by the appropriate factor based upon the number of test conducted.



- e. Outlier values shall be determined as such by the CMT, based upon review of data and information submitted by the Contractor in support of classifying a value as an outlier.
2. In the event that the Contractor or their Precast Manufacturer elects to purchase their own equipment and do their own testing, the laboratory retained shall provide consulting for the testing, and verify adequacy of equipment and proficiency of Contractor or their Precast Manufacturer for conducting ASTM C1609.
3. ASTM C1609 quality control testing proficiency verification of Contractor or their Precast Manufacturer shall be determined as follows.
  - a. Laboratory shall prepare 10 test samples for each of two different fiber dosage rates for a total of 20 samples.
  - b. Laboratory and Contractor or Precast Manufacturer shall each test 5 samples of each fiber dosage rate.
  - c. Laboratory shall label specimens such that there is a log of which fiber dosage is contained within each specimen.
  - d. Contractor or Precast Manufacturer and Laboratory shall conduct simultaneous and separate analysis of test results
  - e. Laboratory shall observe testing conducted by the Contractor or Precast Manufacturer and Contractor or Precast Manufacturer shall observe testing conducted by the Laboratory
  - f. Verification of Contractor or Precast Manufacturer testing proficiency shall be jointly determined by Laboratory and the CMT.

g. If Contractor or Precast Manufacturer is not deemed proficient in conducting ASTM C1609, then the Contractor or Precast Manufacturer shall hire a testing laboratory with the appropriate credentials to conduct quality control testing until such time that the Contractor or Precast Manufacturer may acquire the verified proficiency to conduct the testing.

C. Documentation:

1. The segmental lining production facility shall maintain production control charts for all production and verification test results of concrete and concrete making materials, which include, but are not limited to
  - a. Slump
  - b. Unit Weight
  - c. Fiber content
  - d. Curing Temperatures, times, and durations
  - e. ASTM C1609 test results
  - f. Compressive Strengths
  - g. Flexural Strengths

1.05 SUBMITTALS FOR REVIEW

- A. Prepare Submittals for Review in accordance with Section 01300.
- B. Provide mix design in accordance with Sections 03300 and 02326, for approval by the CMT.
- C. 30 days prior to the commencement of segment production and in addition to the requirements of Section 03300, submit the Means and Method Statements for the following, for approval of the CMT:
  1. Proposed Mix Design(s)
  2. Method for production and assessment of pre-production segments

- a. Batching, including the addition of steel fibers, including equipment and methods of monitoring used.
  - b. Mold cleaning and preparation.
  - c. Concrete placement and vibration.
  - d. Curing.
  - e. Demolding.
  - f. Storage of segments.
  - g. Methods for demonstrating ongoing compliance with segment production, testing and performance requirements.
  - h. Methods for repair and dispositioning and downgrading damaged or non-confirming segments
- D. Submit the performance standards for all materials, the US Standard designation and title they are governed by, and the test results showing compliance of the materials.
1. The same source and types of materials shall be used throughout the duration of the project unless excepted by the CMT.
  2. Any change in materials shall require re-submittal of all information required for review and approval of the CMT.
- E. Submit all data and results for testing required in 1.04 (QUALITY ASSURANCE) of this section
- F. Quality Control:
1. Tests Results of trial mixes for tests specified in Part 3.
  2. Quality records for each segment.
  3. Record of successful trials demonstrating the effectiveness of any automated fiber dosage equipment used.

## 1.06 SUBMITTALS FOR INFORMATION

- A. Prepare Submittals for Information in accordance with Section 01300.
- B. Quality Control:
  - 1. Manufacturers product data:
  - 2. Materials certifications.
  - 3. Record of mold identifier.
  - 4. All raw data for ASTM C1609 testing in excel spreadsheet format, including load, deflection, deflection rate.
- C. Submit all qualifications required by Part 1.04 of this Section 90 days prior to commencing Work related to the Section.
- D. Submit information for all testing equipment to be used by Contractor or Precast Manufacturer. This includes the following
  - 1. Manufacturer's data sheets
  - 2. Current equipment calibrations, and for all equipment to be used for conducting ASTM C1609, the two most recent calibrations.
- E. Submit test laboratory and or agency qualifications and certifications for performing all relevant tests cited herein.
- F. In addition to the submittals required by Section 03300, the Contractor or Precast Manufacturer shall submit the following PRODUCT information:
  - 1. Manufacturer's product data sheets for steel fibers including:
    - a. Physical and mechanical properties.
    - b. Mixing, handling, storage, and waste disposal requirements.

1.07 DESIGN CRITERIA

- A. The following strengths shall be as specified on the Contract Drawings, and the values shall be as shown in Table 03202-1
1. Flexural Strength.
  2. Residual Flexural Strength.
  3. Splitting Tensile Strength.

**TABLE 03202-1: Segmental Lining Performance Requirements**

| Method                    | ASTM C39  | ASTM C1609,<br>Peak strength, $f_p$ | ASTM<br>C496 | ASTM<br>C1609<br>$F_{e3}$ |
|---------------------------|---|-------------------------------------|--------------|---------------------------|
| Value                     | 6000 psi  | 581 psi                             | 387 psi      | 158 psi                   |
| Cement Type               | <p>ASTM C150 Type II, Type V or ASTM C595 IP(HS) or IP(HS) : Total C3A content shall be less than 5%, unless the Portland cement, when tested in accordance with ASTM C452 has an expansion of 0.04% or less at 14 days, per the stipulations of ACI 201.2R: The CMT shall make the determination of the suitability of testing when assessing cementitious materials combinations with greater than 5% total C3A content. Total Equivalent alkalis shall be less than 0.60%</p> <p>ASTM C150 Type I cement shall not be permitted.</p> |                                     |              |                           |
| Minimum Cement Content    | 675 lb / cubic yard   |                                     |              |                           |
| Fly Ash Type <sup>§</sup> | ASTM C618 Class F   |                                     |              |                           |
| Cement Replacement Level  | 25% maximum   |                                     |              |                           |
| Slag Type <sup>§</sup>    | ASTM C989   |                                     |              |                           |

|                                    |                                 |
|------------------------------------|---------------------------------|
| Cement Replacement Level           | 40% maximum                     |
| Silica Fume Type                   | ASTM C1240                      |
| Cement Replacement Level           | Between 5% and 7%               |
| Xypex <sup>®</sup>                 | 2% to 3% of cement / cubic yard |
| ConShield <sup>®</sup>             | One (1) gal / cubic yard        |
| Maximum water / cementitious ratio | 0.35 maximum                    |

<sup>§</sup> Use either slag or fly ash, but not both.

<sup>@</sup>Use either Xypex or ConShield, but not both, per the manufacturer's recommendations.

- B. Performance values or mix constituents and proportions outside those in Table 03202-1 shall only be permitted subject to demonstration that the mix provides the required durability characteristics over the design life to the satisfaction of the CMT.

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## **PART 2 PRODUCTS**

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### 2.01 MATERIALS

- A. Materials shall generally be in accordance with Section 03300 except as modified in this section. Maximum size aggregate shall be ¾ inch.
- B. Total combined chloride content of all materials used in the mix shall not exceed the limits imposed by of ACI 350 for various types of reinforcement.
- C. Steel fiber type shall be selected on the basis of compliance with this specification and on suitability and ease of use in the batching, mixing and concrete placement processes proposed, as demonstrated by site trials.
- D. Fibers shall meet the following requirements:
1. Steel fiber reinforcement shall be deformed and shall conform to ASTM A820, Type I.
  2. Steel Fibers shall have an aspect ratio (l/D) of between 65 and 80.

3. Fibers shall have a minimum length of 2.36 in. (60mm) and minimum tensile strength 152,000 psi (1050 MPa).
4. Fibers minimum dosage rate shall be 15 kg per cubic yard.
5. Fibers which consistently form fiber balls during batching and mixing shall not be used.

## 2.02 EQUIPMENT

- A. Batching plant shall conform to the requirements of Section 03300.
- B. The batching of fibers shall incorporate whole bags of fibers introduced into the mixing cycle in accordance with the manufacturer's recommendations, unless an automated dosing system is used. Where an automated dosing system is used for the batching of the steel fibers the system shall be demonstrated to provide an even distribution of fibers and good control over fiber content for the particular type of fiber used.

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## **PART 3 EXECUTION**

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### 3.01 TRIAL MIXES

- A. Trial mixes shall be commenced a minimum of 4 months prior to production commencing to ensure sufficient time is allowed for a mix to be developed that meets the required test requirements.

### 3.02 BATCHING

- A. Batching shall be in accordance with Section 03300, except for the following requirements specific to steel fiber reinforced concrete:
  1. The mixing procedures adopted for steel fiber reinforced concrete shall follow the recommendations of the fiber manufacturer and shall ensure dispersal of the fibers without balling.

### 3.03 CURING

- A. The method of curing shall prevent the loss of moisture from exposed concrete surfaces. Curing shall continue for the lesser of 7 days or until the concrete has attained at least 70% of the 28-day

compressive strength. The Contractor may apply for a relaxation of this requirement subject to demonstrating that the proposed relaxed requirements provide the required durability characteristics over the design life to the satisfaction of the CMT.

- B. If steam curing is used then it shall comply with the following requirements, for all stages of steam curing in all zones:
1. Steam shall be prevented from impinging directly upon the surface of any segment.
  2. Segments and steam shall be enclosed such that steam and heat are retained within with no significant loss of either
  3. The temperature inside the curing enclosure during primary cure shall be monitored and charted on chart recorder at all times. For secondary cure, visual checks and manual recordings every 2 hours shall be sufficient.
  4. Temperature sensing devices
    - a. Contractor shall submit a means and methods statement for monitoring temperature, which shall include the location and monitoring method of all temperature sensing devices, for approval to the CMT.
  5. Maximum temperature of the concrete shall not exceed 147.8°F
  6. Test samples (cylinders and beams) for segments shall travel with the segments through the curing process.
- C. If the concrete is steam cured for less than the minimum curing period then the concrete shall be kept covered and saturated until the concrete cools to no more than 30°F above ambient and curing is continued. Where practical the Contractor shall confirm the temperature of the concrete during steam curing in the production trials. The steam curing shall be representative of that proposed for production.
- D. Suitability of the curing regime shall be determined on the basis of compressive, flexural, splitting tensile, and residual flexural strengths.



### 3.04 TESTING

- A. Testing shall be in accordance with section 03300, with additional testing as defined in this section.
- B. Fiber content compliance:
  - 1. Fiber content shall be determined for every 150 cubic yards of concrete produced.
  - 2. By valid statistical means, determine the mean fiber weight (average weight of an individual fiber), in grams, for each type of fibers that will be used in this project. Obtain this information from the fiber manufacturer(s)
  - 3. Divide the nominal fiber weight dosage rate per cubic yard by 54 to determine the nominal fiber weight in 0.50 cubic feet material.
  - 4. Obtain a one (1) cubic-foot sample of concrete for every test, in accordance with ASTM C172.
  - 5. Use 0.5 cubic feet of this sample to obtain the unit weight of the concrete, in accordance with ASTM C138.
  - 6. Following measurement of the unit weight, the material used to obtain the unit weight shall be washed free of paste and aggregate, through a sieve, in order to extract all of the fiber from the mix, ensuring that all fibers are captured and retained.
  - 7. Make sure that all fibers are free of all material that might adhere to them except for water
  - 8. Dry the fibers in an oven at 110°C. Weigh fibers on a calibrated scale with a resolution of 0.5 grams every 30 minutes until two successive measurements show no weight loss
  - 9. Multiply the measured weight of fibers in the 0.5 cubic foot sample by 54 and divide the results by the mean fiber weight obtained from the manufacturer to determine the fiber content

10. Determine the actual volume percent of fibers in the sample by dividing volume of fibers (in cubic feet) by 0.5 cubic feet of concrete.
11. Compare the measured volume percent of samples in the fiber by the nominal volume percent of fibers in the mix.
12. Alternatively, automated fiber count equipment may be utilized to measure fiber counts, contingent upon validation against the prescribed manual method presented herein and the explicit review and approval of the CMT.
13. Fiber count is considered acceptable if the fiber content (volume %) of any individual sample is not less than 80% of the value that has been determined to yield the statistically determined required residual flexural strength (158 psi plus the established margin of safety).
14. A measured fiber dosage greater or less than the nominal fiber dosage rate by more than ten percent of the nominal fiber dosage rate is an indication of improper batching or mixing. This is the action level threshold, meaning steps shall be taken immediately to rectify the problem
15. A measured fiber dosage greater than twenty five percent or less than twenty percent of the nominal fiber dosage rate is an indication of improper batching or mixing. This is the threshold level for rejection of all produced product since the last acceptable measurement. Acceptance will resume once the condition has been appropriately demonstrated to be resolved.

C. Flexural beam tests shall be undertaken to ASTM C1609.

1. All statistical calculations and determinations shall be in compliance with ACI 214.
2. A single test set shall consist of 3 beams.
3. The beam results comply with the specified flexural strength at first peak as defined in ASTM C1609 if the minimum flexural strength at first peak is greater than or equal to 581 psi for all specimens.

4. The flexural strength at first peak is that defined in ASTM standard C1609.
5. The residual flexural strength,  $f_{e3}$ , (sometimes called the equivalent residual strength), shall be calculated as the average stress value for a deflection range of 0 inches to 0.12 in. (3mm), which is equal to  $L/150$  for a 6 inch beam, when testing in accordance with ASTM C1609, as determined in the following manner:
  - a.  $f_{e3} = T_{150,3.0}L / (3bd^2) \times 10^3$  MPa, where
    1.  $f_{e3}$  = Equivalent post-crack residual flexural strength for a deflection of 0.12in. (3mm).
    2.  $T_{150,3.0}$  = Toughness (Joules) at 0.12 (3mm) central deflection (area under load deflection curve)
    3.  $L$  = Span in mm
    4.  $b$  = Specimen width in mm
    5.  $d$  = Depth of specimen in mm.
6. The minimum residual flexural strength,  $f_{e3}$  (equivalent residual strength) at 0.12 in. (3mm) deflection, obtained in accordance with ASTM C1609 from a beam with a 6-inch x 6-inch cross section, shall be no less than 158 psi.
7. The residual flexural strength test results are acceptable and compliant with specified residual flexural strength requirements if the following conditions are met.
  - a. The mean residual flexural strength of the three beams required by ASTM C1609 is not less than 158 psi.
  - b. The result of any single individual beam out of the three is not less than 142 psi.

- c. The result of any single individual beam of the three required is not less than 3 standard deviations below the mean of the 3 beams in the test set.
- 8. The failed specimens shall be retained and checked to ensure the random distribution and alignment of the steel fibers to the satisfaction of the CMT. Should the fiber alignment or distribution be noticeably non-random so as to improve the results from the testing above, the tests shall be repeated.
- 9. An individual test result is the average of three beams taken from the same concrete sample.
- 10. Testing frequency shall be as follows:
  - a. One test comprising three samples every day initially, although this may be relaxed subject to demonstrating consistent test results to the satisfaction of the CMT. Samples used to conduct fiber count testing shall be from the same batch.
  - b. The minimum frequency of testing shall never be less than weekly.
  - c. In the event that the testing frequency is reduced, at least three beams shall be cast every day and retained for a minimum period of three months such that they may be available for testing if required in the event of a test failure.
- D. Tensile Splitting Strength shall be determined by testing in accordance with ASTM C496.
- E. Where either residual flexural strength or tensile splitting strengths fail to meet the criteria, for a specific batch, all segments produced with that concrete batch and all preceding batches to the last complying batch shall be considered to be non-conforming. In such cases:
  - 1. The Contractor may undertake additional testing of batches to demonstrate conformance by testing. This may commence with testing of the batch immediately preceding the non-conforming batch, in which case should the batch test be conforming it shall be considered adequate

demonstration of conformance of all preceding batches as well.

2. The Contractor may test the hold beams to gain greater resolution of the time when noncompliance occurred.
3. Where the Contractor believes that a non-conforming test result is an outlier and not representative of the true strength of the concrete then the Contractor may provide evidence to the CMT that the test result is not representative, and that other conforming test results are representative of the affected segments. ACI 214 shall be used as a guide in the determination. In such cases segments shall be considered as conforming subject to approval by the CMT.
4. The CMT may accept non-confirming segments for use:
  - a. in particular locations where the segments are deemed to be of sufficient strength to resist loads in that location, and/or
  - b. if particular additional controls on stacking, lifting and handling are applied to limit applied loads to within the reduced capacity of the segments.

+ + END OF SECTION + +

# APPENDIX K

COST COMPARISON REBAR VS STEEL FIBER SEGMENTS



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**MEMORANDUM**

**TO:** Nicholas Domenick , DOSD **DATE:** May 29, 2014

**FROM:** James Carroll, URS **PROJECT:** Blacklick Creek Sanitary Sewer

**COPIES:** Central File (14577348) **JOB NO.:** 14576007

Irwan Halim, URS **RE:** Cost Comparison Between Traditionally Steel Reinforcement and Steel Fibers

This memorandum provides a cost comparison between traditionally reinforced concrete segments utilizing traditional rebar, a hybrid reinforced segment containing both rebar and steel fibers and a segment containing only steel fibers for reinforcement. These design assumptions are shown on the attached Figure 1. For the purpose of this memorandum only the cost associated with reinforcement is calculated, other segment construction items and materials such as the form work, concrete, concrete inserts, and seals is are not included. Only steel fibers are considered for the Blacklick Creek Sanitary Sewer project due to the higher strength, stiffness, and lower cost when compared to synthetic fibers. Synthetic fibers are traditionally used for fire protection in a tunnel. Note that the application of steel fibers is completed by automation during the mixing process of the concrete; no labor cost is associated with application of steel fibers.

The traditionally reinforced concrete segment design includes traditional reinforcement as shown on the Blacklick Creek Sanitary Sewer 60% design drawings. For the propose of this memorandum it is assume that the rebar reinforcement is 3.45 in<sup>2</sup> of the total 431 in<sup>2</sup> cross-sectional area. Included in the cost for the traditionally reinforced segments are the steel rebar, wire ties, and labor cost associated with the making of the rebar cage and placement of the rebar cage. Total cost of the materials listed in Table 1 below. Labor rates assumed Davis Bacon rates utilizing two (2) laborers for the building and placing the rebar cages.

The hybrid design includes a reduced rebar cage from the 60% design drawings, and inclusion of steel fibers at a dosage rate of 30 kg/m<sup>3</sup> (50.5lb/yds<sup>3</sup>). The reduced rebar reinforcement cage for the hybrid design assumes the rebar will include 1.25 in<sup>2</sup> of the total 431 in<sup>2</sup> cross sectional area. Cost for the hybrid design include rebar, wire ties, labor cost associated with making the rebar cage, placement of the rebar cage, and the steel fibers to be mixed in the concrete. Labor rates assumed Davis Bacon rates utilizing two laborers for the building and placing the rebar cages, the time required to build and place the rebar changes has been reduced in accordance with the reduced cage size when compared to the traditional reinforcement option above.

The full steel fiber reinforcement design for the concrete tunnel segments includes the use of steel fibers at a dosage rate of 50 kg/m<sup>3</sup> (84 lbs/yds<sup>3</sup>). With no rebar reinforcement, the cost associated with the full steel fiber reinforcement option includes the cost of the steel fibers only and no labor is included in this cost. The total cost of the reinforcement for the full steel fiber design is shown in Table 1.

**Table 1 Reinforcement Cost**

|                                    | Traditional Reinforced Concrete Segments | Hybrid Design Concrete Segments | Full Steel Fiber Concrete Segments |
|------------------------------------|--|---------------------------------|------------------------------------|
| Rebar Material Cost                | \$1,669,065.40                           | \$618,568.91                    | \$0                                |
| Rebar Fabrication Cost             | \$1,255,856.10                           | \$627,928.05                    | \$0                                |
| Fiber Material cost                | \$0                                      | \$550,403.40                    | \$935,621.03                       |
| Estimated Total Reinforcement Cost | \$2,924,921.50                           | \$1,796,900.36                  | \$935,621.03                       |