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February 1, 2021

Sent Via Email and Federal Express

Mackinac Straits Corridor Authority
C/O Mr. Ryan Mitchell
Innovative Contracting Manager
Van Wagoner Building
425 W. Ottawa Street
P.O. Box 30050
Lansing, MI 48909

Dear Mr. Mitchell:

In accordance with section 7.2 of the Tunnel Agreement, Enbridge is submitting the jointly developed Project Specifications for approval by the Authority.

Please let me know if you have any questions or require any further information.

Sincerely,

Michael Bagale
Project Director
Great Lakes Tunnel Project

Enclosures (1): Great Lakes Tunnel Project Joint Specifications

CC: Michael Koby - VP US Operations; Lisa Wilson - Associate General Counsel; Peter Holran - Director State Gov Relations; Dave Lawson – VP Major Projects

Specifications Table

SPECIFICATION TITLE	SPECIFICATION SECTION NO.	DATE
Sealing Leaks	310179	December 11, 2020
Earthwork/Excavation and Backfill	312000	December 11, 2020
Diaphragm Walls	315600	December 11, 2020
Backfill Grouting	317117	December 11, 2020
Cast-In-Place Concrete	033000	December 11, 2020
Structural Concrete Materials	033100	December 11, 2020
Precast Structural Concrete	034100	December 11, 2020
Bored Piles	316300	December 11, 2020
Precast Concrete Tunnel Lining	317416	December 11, 2020
Excavation By Tunnel Boring Machine	317119	December 11, 2020

SECTION 310179 – SEALING LEAKS

PART 1 - GENERAL

1.1 SUMMARY

A. Section includes the requirements for furnishing equipment, labor and sealing material and installation or injection as required to seal water leaks into the Straits Tunnel, North Straits Shaft and Mackinaw Station Portal.

B. Related Requirements:
1. Section 033000 “Cast-In-Place Concrete” for placing cast-in-place concrete, including for temporary and permanent support of excavation and for installing waterstops and regroutable hoses.
2. Section 034106 “Precast Structural Concrete Access Tunnel” for providing precast permanent access tunnel units and limits on groundwater inflow in the access tunnel.
3. Section 315600 “Diaphragm Walls” for construction of concrete diaphragm (slurry) walls using to provide a temporary and permanent watertight support of excavation and limits on groundwater inflow through the walls.
4. Section 317117 “Backfill Grouting” for performing backfill grouting and check grouting during tunneling.
5. Section 317119 “Excavation by Tunnel Boring Machine” for completion of the bored tunnel with the use of a Pressurized Face Tunnel Boring Machine (TBM), including installing the permanent tunnel lining consisting of gasketed precast concrete segments and limits on groundwater inflow through the tunnel lining.
6. Section 317416 "Precast Concrete Tunnel Lining" for manufacturing, handling, transporting and installing gasketed precast concrete tunnel lining (PCTL) segments, and for repair of damage to the segments other than leaks.

1.2 DEFINITIONS

A. Leak Sealing: Installation or injection of materials to seal leaks, stopping any soil transport and minimizing groundwater flow through the PCTL and the North Straits Shaft and Mackinaw Station Portal permanent structures.

B. Regroutable Hose: Hose which can be positioned in construction joint and which can be grouted, flushed and regrouted to seal leaks.

1.3 REFERENCES

A. American Concrete Institute (ACI):
1. ACI 224.1R Causes, Evaluation, and Repair of Cracks in Concrete Structures.

B. ASTM International (ASTM):

1. ASTM C321 Standard Test Method for Bond Strength of Chemical-Resistant Mortars.
2. ASTM D93 Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester.
3. ASTM D638 Standard Test Method for Tensile Properties of Plastics.
4. ASTM D695 Standard Test Method for Compressive Properties of Rigid Plastics.
5. ASTM D790 Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials.
6. ASTM D1042 Standard Test Method for Linear Dimensional Changes of Plastics Caused by Exposure to Heat and Moisture.
7. ASTM D1638 Methods of Testing Urethane Foam Isocyanate Raw Materials.
8. ASTM D2240 Standard Test Method for Rubber Property – Durometer Hardness.
9. ASTM D3574 Standard Test Methods for Flexible Cellular Materials – Slab, Bonded, and Molded Urethane Foams.

C. Federal Highway Administration (FHWA):
1. FHWA (2005) Highway and Rail Transit Maintenance and Rehabilitation Manual, FHWA-IF-05-017.

1.4 PRECONSTRUCTION MEETINGS

A. Conduct pre-installation meeting after the submittals required to perform the work have been approved, and at least 48 hours prior to starting leak sealing operations.

B. Pre-construction meeting to be attended by representatives from the Company, Contractor and Designer.

C. As a minimum, review the following:
1. Health, safety and environmental hazards.
2. Emergency plans and response protocols.
3. Material safety data sheets (MSDS) sheets.
4. Specifications.
5. Work plan and construction methods.
6. QC plan.
7. Procedure for initial leak sealing operations, review of effectiveness and modifications to work plan.
8. Reporting requirements.
9. Key personnel involved with the work.
10. Testing and monitoring requirements.
11. Contingency plans.

1.5 ACTION SUBMITTALS

A. Product Data: MSDS, material certificates of compliance and documentation showing that the proposed materials have a history of demonstrable satisfactory performance and are compatible with adjacent materials.
1. Leak sealing materials.

B. Workplan: A description of the leak sealing approach, demonstrating the approach to meeting the specification approach for water inflows, including:
1. Detailed procedure for all leaks to be sealed.

2. Manufacturer's documented procedure for testing and inspection activities.
3. Requirements for the storage, handling, and installation of the products.
4. Details associated with grouting and cleaning regroutable hoses.
5. Updated and resubmitted workplan if grouting methods change.

C. Shop Drawings:
1. Steel plate for sealing over grout socket.

1.6 INFORMATIONAL SUBMITTALS

A. Qualifications:
1. Grouting Manager.
2. Leak Sealing Specialist.

B. Certifications:
1. Weekly calibration certificates for pressure gauges and flow meters.
2. Certification that all admixtures are noncorrosive.

C. Provide leak survey information and grouting records, including location, approach taken, whether sealing is first time or subsequent attempt, hole depth and orientation, sealant used, volume used, time spent, notes on performance and acceptance criteria used to consider sealing work completed in Segment Tracking Database specified in Section 317416 “Precast Concrete Tunnel Lining”.

1.7 QUALITY ASSURANCE

A. Qualifications:
1. Grouting Manager: Minimum of 10 years of related work experience on similar projects to manage the grouting program by designing, testing, and overseeing the injection of grout mixes of the type required.
2. Leak Sealing Specialist: Minimum of 10 years of related work experience.

1.8 PRECONSTRUCTION TESTING

A. Not used.

1.9 DELIVERY, STORAGE, AND HANDLING

A. Not used.

1.10 FIELD CONDITIONS

A. Not used.

PART 2 - PRODUCTS

2.1 GENERAL

A. Sealants for use for remedial repairs shall demonstrate a 100-year design life and strength requirements appropriate to the specific repair.

B. In addition to the sealants specified in the Section, propose additional sealants as needed for approval by the Company, meeting the applicable durability and strength requirements to suit specific leak conditions.

2.2 SINGLE COMPONENT POLYURETHANE

A. Sealant suitable for use for remedial repairs of flush construction joints and shrinkage cracks up to 0.012 inches (0.3mm) wide: A single component polyurethane hydrophilic polymer; which reacts with water to form a tough, expansive, elastic, durable gel with adhesive properties in its cured form. When used without water for crack filling, the material will form a tough, dense, rubbery sealer. Provide a product that exhibits the physical requirements listed in Table 1, or as approved by the Designer.

Table 1: Single Component Polyurethane Physical Requirements

Property	Requirement	Standard
UNCURED		
Solids	83 percent	
Viscosity	650 to 800 CPS	ASTM D1638
Color	Pale Yellow	
Density	8.7 to 9.2 LBS/GL	ASTM D1638
Flashpoint	225 degrees F	ASTM D93
Reaction Time	1/1 W/WATER	20 SEC.
CURED		
Tensile Strength	380 psi	
Elongation	400 percent	ASTM D3574
Bond Strength	250 to 300 psi	ASTM D3574
Shrinkage	less than 10 percent	ASTM D1042
Toxicity	Non-Toxic	

B. Cure Time: As required based on the application.

C. Chemical Compatibility: Provide gel that forms successfully in the presence of the chemicals in the groundwater per the Geotechnical Baseline Report (GBR).

D. Material: No change in linear dimension more than 18 percent when subjected to wet and dry cycles.

2.3 TWO COMPONENT 100% SOLIDS EPOXY RESIN

A. Sealant suitable for use for the repair of the construction joints, shrinkage cracks, and hair line structural cracks wet or dry up to 0.016 inches (0.4mm) alone, and up to 0.032 inches (0.8mm) with the addition of sand: A two component 100% solids, anime, or polyester epoxy resin injection.

B. Meet or exceed the physical properties in Table 2, or as approved by the Designer:

Table 2: Two Component 100% Solids Epoxy Resin Physical Requirements

Property	**Requirement**	
Temperature Range	40 to 100 degrees F	
Consistency	Liquid	
Viscosity	Part A at 77 degrees F plus or minus 3 degrees F	
	60 cps max	
	Brookfield RVT Spindle No. 2 @ 20 rpm	
Viscosity	Part B at 77 degrees F plus or minus 3 degrees F	
	25 cps max	
	Brookfield RVT Spindle No. 2 @ 20 rpm	
Pot Life (60gm.mass)	77 degrees F plus or minus 3 degrees F	
	60 min.	
Compressive Yield Strength	ASTM D695	
	12,500 psi min.	
	7 days at 77 degrees F plus or minus 3 degrees F	
Tensile Strength	10,000 psi	ASTM D638
Bond Strength (dry concrete)	600 psi at 28 days	ASTM C321
Shore Hardness	80	ASTM D2240
Elongation	2 to 5 percent	ASTM D638
Mix Ratio	2:1 by volume (A:B)	

2.4 SWELLING POLYURETHANE SEALANT

A. Sealant suitable for use for sealing leaks at precast segment joints up to 0.012 inches (0.3mm) wide.

B. Swelling water reactive polyurethane polymer sealant with the properties listed in Table 3, or as approved by the Designer:

Table 3: Swelling Polyurethane Sealant Physical Requirements

Property	Requirement	Standard
UNCURED		
Viscosity	Gel/Paste	
Solids	100 percent	
Specific Gravity	1.57	ASTM D1638
Vertical Slump	0.12 inches (3 mm)	
Tack Free	12 hours	
Flashpoint	265 degrees F	
CURED		
Shore Hardness	40A	ASTM D2240
Tensile Strength	265 psi	ASTM D3574
Elongation	600 percent	ASTM D3574
Tear Strength	170 psi	ASTM D790
Expansion (in water)	250 percent	
Toxicity	Non-Toxic	

2.5 GROUT FOR REGROUTABLE HOSES

A. Remedial grout for use in the regroutable hoses: Sika® Injection 306 or Company-approved equal.

2.6 REPAIR MATERIALS

A. Repair materials for filled holes drilled into concrete: In accordance with Section 317416 "Precast Concrete Tunnel Lining."

2.7 INJECTION EQUIPMENT

A. As recommended by manufacturer.

2.8 SOURCE QUALITY CONTROL

A. At a minimum, include the following items in the Inspection and Test Plan:
   1. Surveillance:
      a. Not used.
   2. Review:
      a. Leak sealing materials product data sheets.
      b. Manufacturer recommended installation method.
   3. Verification:
      a. Products comply with specified standards.
   4. Witness Point:
      a. Not used.

5. Hold Point:
   a. Not used.

PART 3 - EXECUTION

3.1 GENERAL

A. Conduct leak surveys and classify categories of leaks based upon width, length, and amount of water infiltration through the structure. Include results of leak survey in Segment Tracking Database specified in Section 317416 “Precast Concrete Tunnel Lining”.

B. Seal concrete leaks in accordance with ACI 224.1R.

C. Seal leaks in the Straits Tunnel if the water ingress limits are in excess of those specified in Section 317119 “Excavation by Tunnel Boring Machine”.

D. Seal leaks in the North Straits Shaft if the water ingress limits are in excess of those specified in Section 315600 “Diaphragm Walls”.

E. Seal leaks in the Mackinaw Station Portal if the water ingress limits are in excess of those specified in Section 315600 “Diaphragm Walls” for leakage through diaphragm walls and Section 034106 “Precast Structural Concrete Access Tunnel” for leakage into the precast permanent access tunnel.

F. Acceptance criteria for the leak sealing is compliance with the specified water ingress limits at completion of construction.

G. Trial each method defined in the work plan on the first leaks to be sealed. Regularly evaluate effectiveness of sealing methods and update as needed to suit project conditions.

H. Perform repairs, including curing time, at a minimum temperature of 50 degrees F unless otherwise approved by Designer, and in accordance with any other temperature limits in manufacturer’s requirements.

3.2 SEALING CRACKS

A. Choose sealant product to suit the particular application and field conditions.

B. Use a drill bit of a size appropriate for the injector probe to drill directly into a crack or construction joint, or drill from one side and intersect the crack or joint at approximately one-half the thickness of the concrete structure. Space holes at approximately one-half the thickness of the concrete. Determine the exact approach taken based on field conditions.

C. Flush grout hole by injection with water. Remove leaching deposits from cracks by abrasive blasting, or wire brushing. Flush cracks with water by pressure through injection ports. Wash out concrete laitance or contaminants through the crack. Remove free water by blowing air under pressure through the crack after flushing.

D. Inject the sealant into the crack or segment to be sealed starting at the lowest point and working up to the highest point, working both sides of the crack or joint simultaneously, move to the next injection point after observing grout return from next packer.

E. Insert the applicator injection probe; pack with approved hydraulic cement or use a short plastic tube as a gasket.

F. Pump sealant until the crack or joint is sealed, back pressure is encountered and a grout return is noted at the crack or joint to be grouted. Follow manufacturer's recommendations.

G. Repeat procedure along full length of the crack or joint until leak is sealed. Split the hole spacing and re-seal as necessary to seal the leak.

H. Mark crack tips on completion of repair to allow crack growth to be evaluated if leakage reoccurs.

3.3 SEALING SEGMENT JOINTS

A. For locations where leakage is occurring through the intrados gasket or through bolt hole:
   1. Drill a minimum of two approximately 0.7 inch diameter holes on the joint through the concrete to the nearest face of the gasket, located at the lowest and highest extents of the compartment formed by the intrados, extrados and cross gaskets.
   2. Insert a drilling needle of 0.15 inch diameter through the gasket, displacing the gasket and not removing any of the gasket material.
   3. Loosen segment bolt to allow flow of sealant through bolt hole.
   4. Choose sealant product to suit the particular application and field conditions.
   5. Insert sealant at low pressure into lower hole until a grout return is seen in the bolt hole, and then tighten bolt to seal bolt hole.
   6. Continue grouting until a grout return is seen in the upper hole.

3.4 SEALING SEGMENT GROUT SOCKETS

A. For locations where leakage is occurring through or around a grout socket that has been used for check grouting, follow procedure for sealing cracks and construction joints by injecting around circumference of grout socket.

B. If unsuccessful with crack sealing methods:
   1. Fabricate and bolt a 12 inch by 12 inch steel plate 0.25 inches thick over the grout socket.
   2. Include a grouting and relief port in the plate sized to be positioned over the grout socket.
   3. Seal the contact between the segment and the plate with an approved repair material.
   4. Once seal has gained strength, grout behind plate with swelling polyurethane sealant until the maximum pressure for check grouting in Section 317117 “Backfill Grouting” is reached.

3.5 SEALING CAST-IN-PLACE CONCRETE JOINTS

A. For joints or other locations where a regroutable hose is located and leakage in excess of the criteria is occurring:

1. Grout all regroutable hoses after concrete has obtained the required strength. Determine injection pressure by means of on-site demonstration; do not exceed structural capacity of the structure.
2. Clean hoses and pipes after grouting.
3. Repeat grouting operation if leakage continues to be higher than the criteria.

B. For construction joints where there is no regroutable hose, follow the procedure for sealing cracks.

3.6 OTHER REPAIRS

A. For other types of leaks, repair in accordance with FHWA Highway and Rail Transit Maintenance and Rehabilitation Manual and ACI 244.1R, as appropriate and accepted by the Designer.

3.7 SURFACE CLEANUP AND FINISH

A. Finish the surface of sealed leaks flush with adjacent concrete surface without indentation or other evidence of port fittings. Point the leak surface flush with an approved repair material and remove excess material from adjacent surfaces; produce a smooth joint.

3.8 FIELD QUALITY CONTROL

A. At a minimum, include the following items in the Inspection and Test Plan:
1. Surveillance:
    a. Leak sealing.
    b. Surface cleanup and finishing.
2. Review:
    a. Leak surveys.
3. Verification:
    a. Leak surveys.
    b. Leak survey in Segment Tracking Database.
    c. Grouting records in Segment Tracking Database.
4. Witness Point:
    a. Leak surveys.
    b. Grouting of regroutable hoses.
    c. Cleaning of regroutable hoses after grouting.
5. Hold Point:
    a. Not used.

END OF SECTION 310179

SECTION 312000 – EARTHWORK/EXCAVATION AND BACKFILL

PART 1 - GENERAL

1.1 SUMMARY

A. Section includes requirements to excavate materials of varying character and subsurface conditions, necessary for construction of structures and other facilities including portal and shaft excavation (including by controlled blasting); to excavate trenches for utilities; to excavate selected material from project site and to obtain borrow material on or off-site for use as specified; to construct embankments, including placing and compacting selected material in connection therewith as specified; to place and compact backfill for structures and other facilities; to backfill and compact trenches; to install subsurface drainage backfill around and below structures and utilities; to remove and replace unsuitable material; to excavate and grade roads, parking areas and driveways; to prepare base and subbase material for the placing of other material thereon.

B. Related Requirements:
1. Section 023200 “Geotechnical Investigations”.
2. Section 033100 “Structural Concrete Materials”.
3. Section 310913 “Geotechnical Instrumentation and Monitoring” for instrumentation and monitoring requirements including protection of instrumentation and monitoring during earthwork and response levels including during blasting.
4. Section 311000 “Site Clearing" for site stripping, grubbing, stripping and stockpiling topsoil, and removal of above- and below-grade improvements and utilities.
5. Section 312319 “Dewatering” for discharge requirements for excavation dewatering.
6. Section 312320 “Water Treatment and Disposal”.
7. Section 312326 “Reuse and Disposal of Excavated Materials”.
8. Section 312500 “Erosion and Sedimentation Controls”.
9. Section 315000 “Excavation Support and Protection" for shoring and bracing of excavations and Digital Excavation Monitoring and Documentation System.
10. Section 316300 “Bored Piles” for excavation of drilled shafts.
11. Section 321100 “Base and Aggregate Surface Courses”.
12. Section 329119 “Topsoil” for preparing and placing topsoil.
13. Section 329200 “Turf and Grasses” for finish grading in turf and grass areas.
14. Section 329300 “Plants” for finish grading in planting areas and tree and shrub pit excavation and planting.
15. Section 334000 “Storm Drainage Systems”.

1.2 DEFINITIONS

A. Air-Overpressure (Airblast): Fluctuating changes in ambient air pressure caused by blasting. Air-overpressure is expressed in units of linear-scale decibels (dBL). Microphones that measure blast-induced air-overpressure have flat frequency response from 2- to 250-Hertz.

B. Backfill: Soil material or controlled low-strength material used to fill an excavation.

1. Initial Backfill: Backfill placed beside and over pipe in a trench, including haunches to support sides of pipe.
2. Final Backfill: Backfill placed over initial backfill to fill a trench.

C. Base Course: Aggregate layer placed between the subbase course and hot-mix asphalt paving or cement concrete pavement.

D. Blaster(s)-in-Charge: The trained and qualified person(s) in charge and responsible for all matters regarding the safe use of explosive materials once they are received from the Magazine Keeper. The Blaster-in-Charge is also responsible for filling out necessary explosive use or blasting report forms and is responsible for returning all unused explosive materials to the Magazine Keeper.

E. Bedding Course: Aggregate layer placed over the excavated subgrade in a trench before laying pipe.

F. Borrow Soil: Satisfactory soil imported from off-site for use as fill or backfill.

G. Buffer Holes: Holes with reduced energy charges drilled adjacent to smoothwall holes or line-drilled holes at the perimeter of the excavation. The explosive charge in buffer holes is generally between 50- and 75-percent of the charge used in normal production blastholes. Buffer holes are usually drilled parallel to adjacent holes at the excavation perimeter.

H. Burden/Spacing Ratio: The ratio value calculated to evaluate the effectiveness of smoothwall blast designs. The ratio value is determined by dividing the burden (distance between smoothwall perimeter holes and the first-row-in blastholes) by the spacing distance between perimeter holes. For example, if perimeter holes are spaced 18-inches apart and the burden distance to the adjacent row of blastholes is 24-inches, the burden/spacing ratio is 1.33 (24/18).

I. Channel Drilling: A method of controlling overbreak and reducing ground borne vibration energy transfer in which a series of overlapping holes are drilled at the perimeter of the excavation to create an air gap.

J. Contaminated Material: As defined in Section 312326 “Reuse and Disposal of Excavated Materials”.

K. Controlled Blasting: Excavation of rock in which the various elements of the blast, i.e., perimeter drilling, hole size, depth, spacing, burden, charge size, distribution, delay sequence, are carefully balanced and controlled to reduce overbreak and lessen damage to rock remaining beyond desired excavation limits and to reduce ground-borne noise and vibration energy transfer associated with blasting. Blasts incorporating effective smoothwall blasting, line-drilling measures, or channel drilling measures would be considered controlled blasts.

L. Drainage Course: Aggregate layer supporting the slab-on-grade that also minimizes upward capillary flow of pore water.

M. Excavation: Removal of material encountered above subgrade elevations and to lines and dimensions indicated.

N. Fill: Soil materials used to raise existing grades.

O. Flowable Fill: Self-compacting cementitious material with a flowable consistency used as an alternative to compacted Granular Fill. Also referred to as controlled low strength material (CLSM) as defined by ACI 229R-94.

P. Line Drilling: A method of controlling overbreak and reducing ground-borne vibration energy transfer, in which a series of very closely spaced holes are drilled at the perimeter of the excavation. Line holes are generally not loaded with explosives; however, in some applications alternating holes may be loaded with light charges using detonating cord.

Q. Magazine Keeper: The person(s) employed by Contractor, who are named in relevant permits as those responsible for receiving explosive deliveries and maintaining all explosive inventory and usage records, and providing safe and secure storage of all explosive materials.

R. Maximum Charge Weight per Delay: For purposes of vibration control, any charges firing within any 8-millisecond time period are considered to have a cumulative effect on vibration and air-overpressure effects. Therefore, the maximum charge per delay equals the sum of the weight of all charges firing within any 8-millisecond period. For instance, if two - 5-pound charges fire at 100-ms and one - 6-pound charge fires at 105-ms, the maximum charge per delay would be 16-pounds [2 x 5 + 6].

S. Peak Particle Velocity (PPV): The maximum of the ground motion velocities measured in the vertical, longitudinal, and transverse directions. PPV is not the vector sum of the three components of motion. Velocity units are expressed in inches per second (in/s).

T. Powder Factor: Explosive distribution expressed in pounds of explosive per cubic yard of rock shot.

U. Primary Initiation: The method whereby the blaster initiates the blast(s) from a remote and safe location.

V. Production Holes: Blast holes in the main body of the rock mass being removed by drilling and blasting.

W. Residential Area: An area containing structures where people normally sleep.

X. Rock: As defined in Geotechnical Baseline Report (GBR).

Y. Scaled Distance: The distance from a blast measured in feet, divided by the square root of the charge per 8-millisecond delay period measured in pounds. These “square root” scaled distance values are used in calculations to limit charge weight per delay for controlling the intensity of blast-induced ground motion. Scaled distance values are expressed in units of feet pounds-0.5.

Z. Smoothwall Blasting (Trim Blasting): A form of controlled blasting used in tunnel, trench, and other underground excavations. With this method, appropriately designed, small diameter, lightly loaded uniform continuous charges are placed in relatively close-spaced holes and timed to fire such that a well-relieved open face provides excellent relief when removing the final burden of rock in front of trim holes drilled at the excavation limits. Smoothwall trim blasts can be fired as separate blasts after mass rock has been blasted and removed or the trim blast can be integrated with adjacent mass blasts if delay timing and other blast design factors ensure that adequate free-face relief is provided for the final rock burden against perimeter charges.

AA. Stemming: Crushed stone, sand, or other inert material placed in the unloaded collar area of blastholes for the purpose of confining explosive charges and limiting rock movement and air-overpressure.

BB. Structures: Buildings, footings, foundations, retaining walls, slabs, tanks, curbs, mechanical and electrical appurtenances, or other man-made stationary features constructed above or below the ground surface.

CC. Subbase Course: Aggregate layer placed between the subgrade and base course for hot-mix asphalt pavement, or aggregate layer placed between the subgrade and a cement concrete pavement or a cement concrete or hot-mix asphalt walk.

DD. Subdrilling: The portion of a blasthole that is drilled below or beyond the desired excavation depth or limit. Subdrilling is generally required to prevent the occurrence of high or tight areas of unfractured rock between blastholes.

EE. Subgrade: Uppermost surface of an excavation or the top surface of a fill or backfill immediately below subbase, drainage fill, drainage course, or topsoil materials.

FF. Unauthorized Excavation: Excavation below subgrade elevations or beyond indicated lines and dimensions without direction by Company.

GG. Utilities: On-site underground pipes, conduits, ducts, and cables as well as underground services within buildings.

1.3 REFERENCES

A. ASTM International (ASTM):
1. ASTM C33/C33M Standard Specification for Concrete Aggregates.
2. ASTM C94/C94M Standard Specification for Ready Mixed Concrete.
3. ASTM C150/C150M Standard Specification for Portland Cement.
4. ASTM C260/C260M Standard Specification for Air-Entraining Admixtures for Concrete.
5. ASTM C618 Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.
6. ASTM C869/C869M Standard Specification for Foaming Agents Used in Making Preformed Foam for Cellular Concrete.
7. ASTM D448 Standard Classification for Sizes of Aggregate for Road and Bridge Construction.
8. ASTM D1140 Standard Test Methods for Determining the Amount of Material Finer than 75-µm (No. 200) Sieve in Soils by Washing.
9. ASTM D1556 Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method.
10. ASTM D1557 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft (2,700 kN-m/m)).
11. ASTM D1876 Standard Test Method for Peel Resistance of Adhesives (T-Peel Test).
12. ASTM D2167 Standard Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method.
13. ASTM D2487 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System).

14. ASTM D2488 Standard Practice for Description and Identification of Soils (Visual-Manual Procedures).
15. ASTM D2937 Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method.
16. ASTM D2940/D2940M Standard Specification for Graded Aggregate Material for Bases or Subbases for Highways or Airports.
17. ASTM D3740 Standard Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction.
18. ASTM D4083 Standard Practice for Description of Frozen Soils (Visual-Manual Procedure).
19. ASTM D4318 Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.
20. ASTM D4832 Standard Test Method for Preparation and Testing of Controlled Low Strength Material (CLSM) Test Cylinders.
21. ASTM D6023 Standard Test Method for Density (Unit Weight), Yield, Cement Content, and Air Content (Gravimetric) of Controlled Low Strength Material (CLSM).
22. ASTM D6913 Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis.
23. ASTM D6938 Standard Test Methods for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth).
24. ASTM D6951 Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications.
25. ASTM E329 Standard Specification for Agencies Engaged in Construction Inspection, Testing, or Special Inspection.

B. American Association of State Highway Transportation Officials (AASHTO):
1. AASHTO T307 Standard Method of Test for Determining the Resilient Modulus of Soils and Aggregate Materials.

C. American Concrete Institute (ACI):
1. ACI 229R-94 Controlled Low Strength Materials (CLSM).

D. Bureau of Alcohol Tobacco and Firearms (BATF):
1. Title XI, Regulation of Explosives (18 U.S.C. Chapter 40; 84 Statute 952), of the Organized Crime Control Act of 1970 (84 Statute 922) and 27 CFR 55.

E. Code of Federal Regulations (CFR):
1. 40 CFR 260 Hazardous Waste Management System: General.
2. 40 CFR 261 Identification and Listing of Hazardous Waste.
3. 40 CFR 262 Standards Applicable to Generators of Hazardous Waste.
4. 40 CFR 263 Standards Applicable to Transporters of Hazardous Waste.
5. 40 CFR 264 Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.
6. 40 CFR 273 Standards for Universal Waste Management.
7. 40 CFR 761 Polychlorinated Biphenlys (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions.
8. 49 CFR 106, 107, 110, 130, 171-179, 180 Pipeline and Hazardous Material Safety Administration Department of Transportation.
9. 49 CFR 383, 387, 390-399 Federal Motor Carrier Safety Administration, Department of Transportation (Transportation of Hazardous Materials).

F. International Society of Explosives Engineers (ISEE):
   1. Guidelines and Practices for Blasting Seismographs.

G. Michigan Department of Transport (MDOT):
   1. MTM 102 Michigan Test Method for Abrasion Resistance of Aggregate by the Los Angeles Machine.
   2. MTM 103 Michigan Test Method for Determination of Insoluble Residue in Carbonate Aggregates.
   3. MTM 107 Michigan Test Method for Sampling Aggregates.
   4. MTM 108 Michigan Test Method for Materials Finer than No. 75 μm (No. 200) Sieve in Mineral Aggregates by Washing.
   5. MTM 109 Michigan Test Method for Sieve Analysis of Fine, Dense Graded, Open Graded and Coarse Aggregates in the Field.
   6. MTM 110 Michigan Test Method for Determining Deleterious and Objectionable Particles in Aggregates.
   7. MTM 411 Michigan Test Method for Compressive Properties of Prefabricated Drainage Systems.

H. Michigan Department of Transport (MDOT) Standard Specifications for Construction:
   1. MDOT Section 902 Aggregates.
   2. MDOT Section 910 Geosynthetics Table 910-1.

I. Michigan Administrative Code (MI Admin C):
   1. MI Admin C 299.9203.

J. State of Michigan Legislative Council:
   1. Part 111, Sec. 11103, Hazardous Waste Management, of the Michigan Natural Resources and Environmental Protection Act, 1994 PA 451, as amended, and its administrative rules.

K. National Fire Protection Association (NFPA):
   1. NFPA 495 Explosive Materials Code.

1.4 PREINSTALLATION MEETINGS

A. Conduct pre-installation meeting at the project site after the submittals required to perform the work have been approved, and at least 5 working days prior to starting the work.

B. Pre-construction meetings will be attended by representatives from the Company, Contractor, Testing Agency, Designer and Special Inspector.

C. Review methods and procedures related to earthwork, excavation and backfill, including, but not limited to, the following:
   1. Health, safety and environmental hazards.
   2. Emergency plans and response protocols.
   3. Coordination of work with utility locator service.
   4. Coordination of work and equipment movement with the locations of tree- and plant-protection zones.
   5. Extent of trenching by hand or with air spade.
   6. Work plans and construction methods.
   7. Specifications and Contractor’s submittals including Inspection and Test Plan (ITP).

8. Daily reporting requirements.
9. Contractor's preparation.
10. Identify the key personnel involved with the work.
11. Contingency plans.

1.5 ACTION SUBMITTALS

A. Product Data: For each type of the following products required:
   1. All soil materials.
   2. Geotextiles and Geogrids.
   3. Flowable fill, including design mixture.
   4. Warning tapes.
   5. Manufacturer's product information sheets and Material Safety Data Sheets (MSDS) for all explosives, blasting agents, primers and initiator products, blasting devices, lightning detectors, blasting mats, and all other blasting equipment.

B. Test Reports: For each on-site and borrow soil material proposed for fill and backfill as follows:
   1. Classification according to ASTM D2487 and results from all testing required to make classification, including ASTM D1140, ASTM D2488, ASTM D 4083, ASTM D4318, ASTM D6913 as applicable.
   2. Laboratory compaction curve according to ASTM D1557.
   3. Results from backfill material qualification tests as defined herein.
   4. Other compliance testing as identified in Section 2.1 herein.

C. Certification:
   1. For borrow soil material, certification that it is not contaminated.

D. Samples for Verification: For the following products, in sizes indicated below:
   1. Geotextile or Geogrid: 12 by 12 inches (300 by 300 mm).
   2. Fill and Backfill Materials: Provide at request of Designer or Company.
   3. Individual blast plan pro-forma.
   4. Blast reports pro-forma.

E. Shop Drawings:
   1. Shop drawings showing backfill materials and placement and compaction sequence for fill and backfill.

F. Work Plan:
   1. Site plan showing the arrangement of plant and equipment associated with earthworks, excavation and backfill, stockpiles, staging areas, containment areas, etc. as needed to perform work including on-site traffic routes.
   2. Proposed overall construction operation sequence including procedures and methods to be used to ensure the adjacent or nearby structures and utilities are protected during the execution of the work.
   3. Details of setting out.
   4. Details of protection of instrumentation and monitoring equipment.
   5. Soil and rock management plan.

G. Blasting Safety Plan: Submit at least 90 days prior to the start of blasting works a blasting safety plan complying with all State, Federal and Local Requirements and including at a minimum the following:
   1. A complete description of the clearing and guarding procedures that will be employed to ensure personnel, staff, visitors, and all other persons are restricted to safe locations during blasting. This information will include details regarding visible warning signs or flags, audible warning signals, method of determining blast areas (all areas affected by any potentially harmful blast effects), access blocking methods, guard placement and guard release procedures, primary initiation method, control of potential radio frequency interference, and the system by which the Blaster-in-Charge will communicate with site security guards.
   2. Detailed description of how explosives will be safely stored, transported, and used at the work sites. Explain how storage magazines and explosive transport boxes and vehicles will satisfy all applicable regulations and safety plan. Indicate how explosives will be inventoried, secured, and guarded to prevent theft or unauthorized use of explosives.
   3. Detailed contingency plans for handling of misfires caused by cutoffs or other causes.
   4. Fire prevention plan details, including smoking policies, procedures, and limitations for work involving any open flames or sparks, description and location of all fire-fighting equipment, and fire-fighting and evacuation plans.
   5. Initial and ongoing blasting and fire-safety training programs.
   6. An outline of the initial blasting safety and applications training program that will be attended by all persons directly involved with blasting operations including blasters, drillers, helpers, and supervisors.
   7. Description of the personal protective equipment that will be used by Contractor's personnel.
   8. Emergency response procedures.

H. General Blasting Plan: Submit for at least 90 days prior to start of blasting works a General Blasting Plan for all excavation areas where blasting is proposed, prepared by the Contractor's Blasting Consultant and submitted under a signed letter from the Blasting Consultant. Include at a minimum:
   1. Methods of drilling, including equipment descriptions, hole alignment techniques, and measures that will be used to prevent excessive blasthole deviation.
   2. Plan drawings showing typical hole locations, diameter and spacing for burn-cut and relief holes, production blastholes, and for line-drilled, channel-drilled or smoothwall holes at the excavation perimeter.
   3. Additional plan drawings showing typical firing sequence for explosively loaded holes, including delay periods and delay times.
   4. Additional plan drawings indicating how typical firing sequence will be implemented using the chosen initiator system.
   5. Description of methods to assure proper implementation of initiator sequence, including placement of appropriate detonators into boreholes, connection of individual detonators, and connection to the initiation system (blasting machine or other initiator).
   6. Vertical section drawings for typical production blastholes, and for line-drilled or smoothwall holes, showing typical diameter and length, and location, distance, and direction of existing nearby structures relative to line drilling.
   7. Indicate hole-charging methods on vertical section drawings for explosively-loaded holes, including detonator and primer location and make-up, charge placement, and stemming length and type. Also indicate tamping or non-tamping of charges along length of explosive column on drawings.

8. Vibration Control Calculations: A detailed description of how blasts will be conducted in conformance with limitations described herein and within Section 310913 "Geotechnical Instrumentation and Monitoring" based upon test blasts and resultant calculations.
9. Methods for preventing spills or losses of explosives, drilling fluids, oil, or any other pollutants to the ground during all handling and hole charging operations. Include details of all containment and contingency plans for quickly and effectively cleaning up any spilled materials.
10. Methods for safe and approved disposal of all explosive packaging materials.
11. Methods of addressing unusual circumstances, including misfires, substantial changes in ground conditions, loss, or misplacement of explosives, etc.
12. If Contractor intends to blast within 100-feet of cast-in-place concrete that is aged less than 28 days, include details of controlled blasting techniques that will be used to prevent damage to the concrete. Indicate the age of the concrete at the time of blasting, and include calculations indicating levels of expected strain in the concrete. Indicate how strain levels in the concrete generated by such blasting will be monitored and reported to the Designer.

I. Individual Blast Plans: Signed by Blaster-in-Charge, submit to Company and Designer for approval at least 24 hours prior to drilling any blast holes. Include at a minimum:
   1. Proposed date and time of the blast.
   2. Drawings showing:
      a. The location, orientation, and number of blastholes relative to specific stations, slopes, and elevations.
      b. The location, orientation, and number of any line-drilled, channel-drilled, or smoothwall holes drilled at excavation perimeters.
      c. Detonator quantities, types, delays, firing times, and connections.
      d. Borehole diameter, and amount, type, weight, and linear loading density of explosive in all blastholes.
   3. A table showing the weight of explosive per hole, total weight of each explosive used, maximum charge weight per delay, and powder factor.
   4. Scaled distance to nearest surface structure, and nearest subsurface structure, including foundations of buildings and utilities.
   5. If required, submit information deemed pertinent by the Designer such as measures to control flyrock, vibration, air-overpressure, or other blast effects.

J. Inspection and Test Plan: Submit for approval.

1.6 INFORMATIONAL SUBMITTALS

A. Qualification Data: Resumes or documentation of experience demonstrating the following individuals or companies meet the experience requirements identified in the Quality Assurance requirements:
   1. Blasters-in-Charge (submit 90 days prior to commencing the work).
   2. Blasters (submit 90 days prior to commencing the work).
   3. Blasting Consultant (submit 90 days prior to commencing the work).
   4. Earthwork Contractor.
   5. Seismic Survey Agency.
   6. Land Surveyor.
   7. Geotechnical Testing Agency.

B. Minutes of preinstallation meeting: Submit to Company and Designer for information within 48 hours of meeting.

C. Certificates:
   1. Submit calibration certificates for all equipment to be used in the field for survey and for earthwork testing at least 5 days prior to use on site.
   2. Certificates and licenses for all relevant training for all personnel involved in blasting works.

D. Existing Conditions: Documentation of existing trees and plantings, adjoining construction, adjacent property, and site improvements that establishes preconstruction conditions that might be misconstrued as damage caused by the activities described herein.
   1. Use sufficiently detailed photographs or video recordings.
   2. Include plans and notations to indicate specific pre-existing damage conditions of each adjacent property or structure designated to remain.

E. Record Drawings:
   1. Submit as-built drawings of backfill.

F. Test Reports: Submit for all preconstruction and field testing as required herein, including the following for all backfill materials used:
   1. Results of backfill material qualification tests.
   2. Results of field density tests.

G. Blasting Permits:
   1. Provide in accordance with all Federal, State and Local Regulations at least 60 days prior to commencement of blasting operations.

H. Blast Reports: Provide to Company and Designer on the day following any blasting work. Signed and maintained by Blaster-in-Charge. Include at a minimum:
   1. Location of the blasting.
   2. Unusual occurrences including rock falls, unstable ground, groundwater problems, work delays, equipment malfunction, and the location of each occurrence.
   3. Complete description of each blast including:
      a. Date, time, and limits of blast by location.
      b. Amount of each type of explosive used by weight and number of cartridges, as well as total explosive weight used.
      c. Total number of delays used and number of holes used for each delay.
      d. On a diagram of accepted blast pattern, indicate each hole not drilled, drilled but not loaded, changes in spacing or in pattern delays, or in loading holes.
      e. Total number of holes, maximum charge per hole, and corresponding hole number.
      f. Evaluation of blast indicating tights, areas of significant overbreak, and recommended adjustment for the next blast.
      g. Blast monitoring recording times.

I. Vibration and Air-Overpressure Monitoring Results: Provide to Company and Designer weekly.

J. Survey:
   1. Seismic survey report from seismic survey agency.

K. Pre-excavation Photographs or Videotape: Show existing conditions of adjoining construction and site improvements, including finish surfaces that might be misconstrued as damage caused by earthwork, excavation or backfill operations. Submit before work begins.

L. Pre-Blast Certification:
1. Before each blast, certify in writing to the Company and Designer that all installations and operations have been completed in accordance with approved blasting plans as described herein.

1.7 QUALITY ASSURANCE

A. Qualifications:
1. Blasters-in-Charge: Individuals with a minimum of ten years of experience and three projects of similar scope and complexity (or as accepted by the Designer) in similar excavations, rock and controlled blasting techniques, directly related to underground excavation and controlled blasting work.
2. Blasters and Supervisors: Qualified and licensed in accordance with applicable Federal, State, and Local regulations.
3. Blasting Consultant: Retain the services of an experienced independent Blasting Consultant(s) with at least 20 years' experience (or as accepted by the Designer) in preparing controlled blasting designs for underground excavation operations on projects of similar scope and complexity. Retain a Blasting Consultant who has thorough knowledge of all blasting methods used to control overbreak and damage to rock remaining in excavation support walls.
4. Earthwork Contractor: An experienced contractor that has specialized in earthwork with at least 10 years' experience on projects of a similar scale, in similar ground conditions and similar climate.
5. Seismic Survey Agency: An independent testing agency, acceptable to authorities having jurisdiction, experienced in seismic surveys and blasting procedures to perform the following services:
    a. Report types of explosive and sizes of charge to be used in each area of rock removal, types of blasting mats, sequence of blasting operations, and procedures that will prevent damage to site improvements and structures on project site and adjacent properties.
    b. Seismographic monitoring during blasting operations.
6. Land Surveyor: Professional Surveyor licensed in the State of Michigan.
7. Special Inspector for Geotechnical Testing: Qualified according to ASTM E329 and ASTM D3740 for testing indicated.

B. Inspections:
1. Subgrade Inspection:
    a. Notify Designer and Special Inspector when excavations have reached required subgrade.
    b. If Designer or Special Inspector determines that unsatisfactory soil is present, continue excavation and replace with compacted backfill or fill material as directed.
    c. Reconstruct subgrades damaged by freezing temperatures, frost, rain, accumulated water, or construction activities, as directed by Designer or Special Inspector.
2. Fill Inspection:
    a. Notify Designer and Special Inspector when fill is being placed.

b. If Designer or Special Inspector determines that fill placement or compaction does not meet the requirements herein, remove and replace fill to satisfaction of Designer or Special Inspector.
c. Reconstruct fill damaged by freezing temperatures, frost, rain, accumulated water, or construction activities, as directed by Designer or Special Inspector.

C. Testing:
1. Engage a Special Inspector to perform geotechnical field tests and inspections and prepare test reports.
2. Make provisions for observations and testing of the work by the Special Inspector.
a. The responsibilities of the Special Inspector do not include supervision or direction of the actual work of the Contractor.
b. Neither the presence of the Special Inspector, nor any observations and testing performed by them, nor failure to give notice of defects excuses the Contractor from defects discovered in the work.

1.8 PRECONSTRUCTION TESTING

A. Backfill Material Qualification Tests: Complete and submit results for the following prior to use of any material in the work:
1. Classification according to ASTM D2487 and results from all testing required to make classification, including ASTM D1140, ASTM D2488, ASTM D 4083, ASTM D4318, ASTM D6913 as applicable.
2. Laboratory compaction curve according to ASTM D1557.
3. Laboratory Resilient Modulus for the subgrade layers according to AASHTO T 307.
4. For materials requiring compliance with MDOT standards, all relevant testing as specified in MDOT Section 902 Aggregates.

B. Test Blasts:
1. Before any production blasting, perform a series of test blasts to collect data for the following purposes:
a. To determine minimum scaled distances for design of production blasts.
b. To determine means, methods, and procedures to limit potential blast impacts on sensitive structures and facilities, including the effectiveness of measures to minimize overbreak or damage to support-of-excavation walls.
2. Contractor's Blasting Consultant(s) and at least one qualified technical representative from the explosive supplier are required on site to facilitate test-blasting activities.
3. Conduct a minimum of 3 test blasts at each site of blasting works.

1.9 DELIVERY, STORAGE, AND HANDLING

A. Do not contaminate aggregate during loading or measurement. Transport and place aggregate without loss of material.

B. Storage of Soil Materials:
1. Stockpile borrow soil materials and excavated satisfactory soil materials without intermixing. Place, grade, and shape stockpiles to drain surface water. Cover to prevent windblown dust.

2. Stockpile soil materials away from edge of excavations. Do not store within drip line of remaining trees.

1.10 FIELD CONDITIONS

A. Anticipated geotechnical conditions are presented in the Geotechnical Baseline Report (GBR) and Geotechnical Data Reports (GDRs).

B. Visit the site to review all details of the work and working conditions, to verify dimensions in the field including headroom and interference from adjacent or existing structures, and to advise the Designer of any discrepancy before performing any work.

C. Document existing conditions of existing trees and plantings, adjoining construction, adjacent property, and site improvements to establish preconstruction conditions that might be misconstrued as damage caused by the activities described herein.

D. Verify continually during construction that field conditions are as anticipated. Report deviations from anticipated conditions to Designer and Company.

E. Verification: Document and record field conditions during shaft and portal excavations as follows:
   1. Observe and record as-encountered soil and rock conditions.
   2. Provide safe access for geological mapping of rock excavation walls to be prepared by a suitable qualified engineer or geologist who is a Registered Professional Engineer licensed in the State of Michigan, or other qualification approved by the Company. Prepare maps to a scale of 1-inch equals 10 feet. Provide rock mass descriptions in accordance with the project system as presented in the GBR and GDR and supplemented by the International Society for Rock Mechanics (ISRM) Suggested Method for Quantitative Description of Rock Masses. In addition, record top of sound rock, lithology, discontinuity orientation, and groundwater conditions. Append descriptive text to maps to expand upon map information. Provide lower-hemisphere polar projection stereo plots referenced to the maps recording the orientation of discontinuities.
   3. Core Drilling:
      a. Obtain 10-ft lengths (min) of nominal 2.4-inch diameter using diamond core methods. Perform core drilling in accordance with Section 023200 “Geotechnical Investigations”.
      b. Store and label each sample in a core box in accordance with Section 023200 “Geotechnical Investigations”.
      c. Recover cores at the following minimum sampling frequencies:
         1) Mackinaw Station Portal Excavation: 1 per 3000 cu. yd.
         2) North Straits Shaft Excavation: 1 per 1000 cu. yd.
   4. Grab Samples:
      a. In the overburden soils retrieve 10-lb (minimum) grab samples from across the excavation at the following minimum sampling frequencies:
         1) Mackinaw Station Portal Excavation: 1 per 500 cu. yd.
         2) North Straits Shaft Excavation: 1 per 250 cu. yd.
      b. Preserve samples in heavy duty plastic sample bags for possible future examination and testing. Clearly record the following information on the sample bag: “Project,” “Agreement No.”, “Sample ID,” “Date,” and any other necessary data requested by

the Company. Reference the sample ID to a discrete location within the excavation, including both the spatial location and elevation.

5. Store samples in a storage facility in accordance with specification Section 023200 “Geotechnical Investigations”.
6. Laboratory testing requirements are not included in this specification. In the event of a potential variation from the baseline parameters presented in the Geotechnical Baseline Report, perform testing as agreed with the Company.

F. Vibration Control: Limit vibration due to construction to prevent damage to adjacent buildings, structures, utilities, and all other facilities.

G. Existing Pipelines: Protect existing pipelines from any construction impacts.

H. Traffic: Minimize interference with adjoining roads, streets, walks, and other adjacent occupied or used facilities during earth-moving operations.
1. Do not close or obstruct streets, walks, or other adjacent occupied or used facilities without permission from Company and authorities having jurisdiction.
2. Provide alternate routes around closed or obstructed traffic ways if required by Company or authorities having jurisdiction.

I. Improvements on Adjoining Property: Comply with requirements of Agreement and Exhibits, including with respect to right-of-way and limits of disturbance. Do not proceed with work on adjoining property until directed by Company.

J. Utility Locator Service:
1. Notify utility locator service MISS DIG 811 before beginning earthwork, excavation and backfill operations.
2. Indicated locations of existing facilities and systems are approximate. Investigate and determine exact location and nature of utilities, facilities and systems, and be solely responsible for damages caused by construction activities.

K. Do not commence earth-moving operations until the following measures are in place:
1. Temporary site fencing and erosion- and sedimentation-control measures specified in Company’s Environmental Protection Plan and Permits and Section 311000 "Site Clearing".
2. Plant-protection measures specified in Company’s Environmental Protection Plan and Permits.

L. The following practices are prohibited within protection zones:
1. Storage of construction materials, debris, or excavated material.
2. Parking vehicles or equipment.
3. Foot traffic.
4. Erection of sheds or structures.
5. Impoundment of water.
6. Excavation or other digging unless otherwise indicated.
7. Attachment of signs to or wrapping materials around trees or plants unless otherwise indicated.
8. Heat sources, flames, ignition sources, and smoking.
9. Do not direct vehicle or equipment exhaust towards protection zones.

M. Dewatering: Prevent water from accumulating in excavation. Dewater as required, complying with the requirements of Section 312320 “Water Treatment and Disposal”.

N. Dust Control: As specified in Company’s Environmental Protection Plan and Permits.

PART 2 - PRODUCTS

2.1 SOIL MATERIALS

A. Provide borrow soil materials when sufficient satisfactory soil materials are not available from excavations.

B. General Fill and Backfill:
   1. Satisfactory Soils:
      a. Soil Classification Groups GW, GP, GM, SW, SP, and SM according to ASTM D2487 or a combination of these groups; free of rock or gravel larger than 3 inches (75 mm) in any dimension, debris, waste, frozen materials, vegetation, and other deleterious matter.
         1) Plasticity Index: <15%.
         2) Expansion Index: <20%.
         3) Organic content <3%.
   2. Unsatisfactory Soils:
      a. Soil Classification Groups GC, SC, CL, ML, OL, CH, MH, OH, and PT according to ASTM D2487, or a combination of these groups.
      b. Unsatisfactory soils also include satisfactory soils not maintained within 2 percent of optimum moisture content at time of compaction.
      c. Unsatisfactory soils also includes contaminated material, where contaminated material is material containing any of the following:
         1) Hazardous waste as defined in R 299.9203 of the Michigan Administrative Code.
         2) Hazardous waste as defined in Sec. 11103 of Part 111, Hazardous Waste Management, of the Michigan Natural Resources and Environmental Protection Act.
         3) Any hazardous waste or hazardous constituent listed in 40 CFR part 261, appendix VIII or 40 CFR part 264, appendix IX.
         4) Any substance in soil or water that poses a human health risk and exceeds naturally occurring levels.
   3. For fill beneath roads and pavements, provide material with minimum estimated modulus of 5,000 psi in accordance with AASHTO T 307.

C. Granular Fill:
   1. Naturally or artificially graded mixture of natural or crushed gravel, crushed stone, and natural or crushed sand.
   2. Conform to the following gradation to MTM 109, unless approved otherwise by Designer:

Table 1: Granular Fill Gradation

Sieve Size	Percent Passing (%)
6”	100
3”	95 – 100
#4	50 – 100
#200	0 – 15

3. Plasticity index less than 15 and an expansion index less than 20.
4. Free of debris, waste, hazardous materials, frozen materials, organic materials, vegetation, and other deleterious or corrosive matter.
5. Less than three percent organic content by weight.
6. Maintained within 2 percent of optimum moisture content at time of compaction.
7. Quarried carbonate (limestone or dolomite) cannot be used for any application subject to vehicular traffic.
8. For fill beneath roads and pavements, use material with minimum estimated modulus of 5,000 psi in accordance with AASHTO T 307.

D. Structural Fill:
1. Naturally or artificially graded mixture of natural or crushed gravel, crushed stone, and natural or crushed sand.
2. Conform to the following gradation to MTM 109:

Table 2: Structural Fill Gradation

Sieve Size	Percent Passing (%)
3”	100
1-1/2”	85 – 100
1”	60 – 100
#4	50 – 100
#100	0 – 30
#200	0 – 7

3. Plasticity index less than 15 and an expansion index less than 20.
4. Free of debris, waste, hazardous materials, frozen materials, vegetation, and other deleterious or corrosive matter.
5. Less than three percent organic content by weight.
6. Maintained within 2 percent of optimum moisture content at time of compaction.
7. Quarried carbonate (limestone or dolomite) cannot be used for any application subject to vehicular traffic.
8. For fill beneath roads and pavements, use material with minimum estimated modulus of 5,000 psi in accordance with AASHTO T 307.

E. Subbase:
1. Refer to requirements in Section 321100 “Base and Aggregate Surface Courses”.

F. Aggregate Base Course:
1. Refer to requirements in Section 321100 “Base and Aggregate Surface Courses”.

G. Bedding Course:
1. Naturally or artificially graded mixture of natural or crushed gravel, crushed stone, and natural or crushed sand; ASTM D2940/D2940M; except with 100 percent passing a ¾ - inch (19-mm) sieve and not more than 8 percent passing a No. 200 (0.075-mm) sieve.

H. Drainage Course:
1. Narrowly graded mixture of washed crushed stone or crushed or uncrushed gravel conforming to ASTM D448.

2. Conform to the following gradation to MTM 109:

Table 3: Drainage Course Gradation

Sieve Size	Percent Passing (%)
1-1/2”	100
1”	95 – 100
1/2”	30 – 60
#4	0 – 8
#200	≤1

1. Maximum Los Angeles Abrasion (MTM 102): 40%.
2. Maximum Soft Particles (MTM 110): 3%.
3. Maximum Chert (MTM 110): 7%.
4. Maximum sum of Soft particles and Chert (MTM 110): 9%.

I. Filter Material:
1. Narrowly graded mixture of natural or crushed gravel, or crushed stone and natural sand; ASTM D448; coarse-aggregate grading Size 67; with 100 percent passing a 1-inch (25-mm) sieve and zero to 5 percent passing a No. 4 (4.75-mm) sieve.

J. Sand:
1. ASTM C33/C33M; fine aggregate.

K. Impervious Material:
1. ASTM D2487; clay.

L. Landscape Fill:
1. Satisfactory Soils:
   a. Soil Classification Groups SW, SP, and SM according to ASTM D2487 or a combination of these groups; free of rock or gravel, debris, waste, frozen materials, vegetation, and other deleterious matter.
      1) Plasticity Index: <15%.
      2) Expansion Index: <20%.
      3) Organic content <3%.
2. Unsatisfactory Soils:
   a. Soil Classification Groups GW, GP, GM, GC, SC, CL, ML, OL, CH, MH, OH, and PT according to ASTM D2487, or a combination of these groups.
   b. Unsatisfactory soils also include satisfactory soils not maintained within 2 percent of optimum moisture content at time of compaction.
   c. Unsatisfactory soils also includes contaminated material, where contaminated material is material containing any of the following:
      1) Hazardous waste as defined in R 299.9203 of the Michigan Administrative Code.
      2) Hazardous waste as defined in Sec. 11103 of Part 111, Hazardous Waste Management, of the Michigan Natural Resources and Environmental Protection Act.
      3) Any hazardous waste or hazardous constituent listed in 40 CFR part 261, appendix VIII or 40 CFR part 264, appendix IX.
      4) Any substance in soil or water that poses a human health risk and exceeds naturally occurring levels.
3. For fill beneath roads and pavements, provide material with minimum estimated modulus of 5,000 psi in accordance with AASHTO T 307.

2.2 GEOTEXTILES

A. Geosynthetics must be composed of long-chain synthetic fiber of at least 85 percent, by weight, polyolefins or polyesters. Geosynthetics must be capable of resisting degradation from chemicals, mildew, rot, and ultraviolet (UV) light.

B. Deliver and store geosynthetics in packaging capable of resisting UV radiation, contaminants, and moisture. Label each unit of material with product information including supplier and lot identification. Do not expose geosynthetics to direct sunlight for prolonged periods. Repair or replace damaged geosynthetics.

C. Geotextiles are flexible, permeable fabrics, consisting of synthetic fibers or yarns oriented into a dimensionally stable network. Woven geotextiles must have sealed or selvaged edges to prevent raveling.

D. Geotextiles must meet the relevant minimum physical property requirements shown in Table 910-1 of MDOT Specification Section 910. Where directional property values are listed, specify values for the weaker principle direction.

1. Geotextile Blanket: Geotextile for filtration applications, including trench lining, ditch lining, streambed protection, pipe wrap, joint wrap, drainhole and weephole filter, granular blanket separation, and filter bags must be non-woven.
2. Geotextile Liner: Geotextile for erosion control in riprap and similar applications must be non-woven.
3. Geotextile Separator: Geotextile used to prevent intermixing of dissimilar aggregate or soil layers must meet the requirements shown in Table 4 for geotextile separator. Geotextiles separators with grab tensile elongation-at-break less than 50 percent must meet the requirements shown in Table 4 for woven geotextile separator. Geotextiles with grab tensile elongation-at-break equal to or greater than 50 percent must meet the strength requirements shown in Table 4 for non-woven geotextile separator.
4. Stabilization Geotextile: Geotextile used to prevent intermixing of soft subgrade and subbase materials.

Table 4: MDOT Specification Section 910, Table 910-1

Table 910-1
Physical Requirements for Geotextiles

	Property					
	Grab Tensile Strength (min) (lb)	Trapezoid Tear Strength (min) (lb)	Puncture Strength (min) (lb)	Mullen Burst Strength (min) (psi) (a)	Permittivity per second	Apparent Opening Size (max) (mm)
	Test Method					
Geotextile Category	ASTM D 4632	ASTM D 4533	ASTM D 4833	ASTM D 3786	ASTM D 4491	ASTM D 4751 (b)
Geotextile Blanket (c)	90	45	45	140	0.5	0.21
Geotextile Liner	200	75	75	200	0.5	0.21
Heavy Geotextile Liner	270	100	100	400	0.5	0.21
Woven Geotextile Separator (<50% elongation)	270	100	100	400	0.05	0.425
Non-Woven Geotextile Separator (>50% elongation)	200	75	75	200	0.05	0.425
Stabilization Geotextile	270	100	100	400	0.05	0.50
Silt Fence	100 (d)	45	—	—	0.1	0.60
Drainage Geocomposites (e)	90	45	65 (e)	200 (e)	0.5	0.21

a. ASTM D 3786-87. The fluid displacement rate for the Mullen burst test equipment must be 170 mL/min ±5 mL/min. Subtract tare strength from the ultimate burst strength as specified in ASTM.
b. The Engineer will allow filtration opening size (FOS, Canadian General Standards Board, method 148.1 No. 10) as an alternate test method to ASTM D 4751 for non-woven geotextiles.
c. For pipe wrap where backfill around the pipe meets granular material Class II requirements; geotextiles, including knitted polyester sock, which meet the following minimum requirements in the applied condition are permitted: Mass/Unit Area: 3.0 oz/yd²; Mullen burst strength: 100 psi; maximum apparent opening size must be 0.30 mm for pavement and foundation underdrains, and 0.60 mm in other areas.
d. Elongation at the specified grab tensile strength no greater than 40% for silt fence.
e. Geotextile placed over a continuous tubular core must have at least 100 psi Mullen burst strength and 40 lb minimum puncture strength.

E. Drainage Geocomposites:
   1. Drainage geocomposites must meet the requirements shown in MDOT Specification Section 910 Table 910-1.
   2. Prefabricated geocomposites for drainage applications must consist of a geotextile bonded to or wrapped around a polymer core having corrugated, dimpled, tubular, or net (mesh) configurations.
   3. Geocomposites must have sufficient flexibility and durability to withstand installation, handling, and permanent loading stresses.
   4. Fittings for geocomposite installations must be manufactured by the geocomposite manufacturer or meet the published specifications of the geocomposite manufacturer. Tape used to seal connections must be manufactured with adhesive resistant to moisture and organic growth and recommended by the manufacturer for underground service conditions.
      a. Prefabricated Drainage System (PDS): PDS for underdrain applications must consist of a polymer core, completely wrapped with geotextile. The geotextile must be tightly stretched around the core and bonded to itself, to the core, or both. Geotextile must have a peel strength of at least 35 pounds per foot when tested in accordance with ASTM D 1876. Core must be at least 1 inch thick and allow transverse flow from both directions. The geocomposite must have a crush strength of at least 6,000 pounds per square foot at no greater than 18 percent deformation, when tested in accordance with MTM 411.
      b. Wall Drain: Wall drains for single direction cross-planar flow must consist of an impermeable polymer core, with geotextile bonded to one side. The geocomposite must have a minimum crush strength of 4,000 pounds per square foot at no more than 18 percent deformation when tested according to MTM 411.

2.3 CONCRETE MATERIALS

A. Flowable Fill:
   1. Self-compacting low-density, flowable concrete material produced from the following:
      a. Portland Cement: ASTM C150, Type I, Type II or Type III.
      b. Fly Ash: ASTM C618, Class C or F.
      c. Normal-Weight Aggregate: ASTM C33, 3/4-inch (19-mm) 3/8-inch (10-mm) nominal maximum aggregate size.
      d. Foaming Agent: ASTM C869.
      e. Water: ASTM C94.
      f. Air-Entraining Admixture: ASTM C260.
   2. Produce low-density, flowable fill material with the following physical properties:
      a. As-Cast Unit Weight: As stated on Agreement Drawings. Measured at point of placement, when tested according to ASTM D6023.
      b. Compressive Strength: As stated on Agreement Drawings. Tested according to ASTM D4832.

2.4 RIPRAP

A. Comply with requirements of Section 334200 “Stormwater Conveyance”.

2.5 EXPLOSIVE MATERIALS

A. Only use explosives and blasting systems approved by Federal, State and Local regulations.

B. Keep explosives, blasting agents, primers, initiators, and ancillary blasting materials in original packaging with clearly marked date codes. Use only explosives and initiating devices less than one year old or within manufacturer's shelf life limits, whichever are more stringent.

C. If Contractor, Blaster-in-Charge, Blasting Consultant, Company, or Designer determines that a blasting product appears to be in a damaged or deteriorated condition, do not use the suspect product. Immediately return products found to be damaged or in a deteriorated condition to the supplier for safe disposal.

2.6 ACCESSORIES

A. Warning Tape: Acid- and alkali-resistant, polyethylene film warning tape manufactured for marking and identifying underground utilities, 6 inches wide and 4 mils (0.1 mm) thick, continuously inscribed with a description of the utility. Comply with color requirements of MDOT and Company.

B. Detectable Warning Tape: Acid- and alkali-resistant, polyethylene film warning tape manufactured for marking and identifying underground utilities, a minimum of 6 inches wide and 4 mils (0.1 mm) thick, continuously inscribed with a description of the utility, with metallic core encased in a protective jacket for corrosion protection, detectable by metal detector when tape is buried up to 30 inches (750 mm) deep. Use where stated on Agreement Drawings. Comply with color requirements of MDOT and Company.

2.7 SOURCE QUALITY CONTROL

A. At a minimum, include the following items in the Inspection and Test Plan:
   1. Surveillance:
      a. Not used.
   2. Review:
      a. Calibration certificates for all equipment to be used in the field for survey and for earthwork testing.
   3. Verification:
      a. Test results for all source materials in accordance with requirements herein.
   4. Witness Point:
      a. Not used.
   5. Hold Point:
      a. Not used.

B. Source imported aggregates from suppliers able to demonstrate compliance with the requirements of MDOT Section 902 Aggregates.

C. If on-site soils are used, crush, screen, and process as required to meet relevant material requirements herein.

PART 3 - EXECUTION

3.1 PREPARATION

A. Protect structures, utilities, sidewalks, pavements, and other facilities from damage caused by settlement, lateral movement, undermining, washout, and other hazards created by earthwork, excavation and backfill operations.

B. Install instrumentation in accordance with Section 310913 “Geotechnical Instrumentation and Monitoring”.

C. Install erosion and sedimentation controls in accordance with Section 312500 “Erosion and Sedimentation Controls”. Protect and maintain erosion and sedimentation controls during earthwork, excavation and backfill operations.

D. Protect subgrades and foundation soils from freezing temperatures and frost. Remove temporary protection before placing subsequent materials.

3.2 DEWATERING

A. Comply with requirements of Section 312319 “Dewatering” and Section 312320 “Water Treatment and Disposal”. Do not commence dewatering until all submittals required under these specifications are submitted and approved.

B. Provide dewatering system of sufficient scope, size, and capacity to control hydrostatic pressures and to lower, control, remove, and dispose of ground water and permit excavation and construction to proceed on dry, stable subgrades.

C. Prevent surface water and ground water from entering excavations, from ponding on prepared subgrades, and from flooding project site and surrounding area.

D. Protect subgrades from softening, undermining, washout, and damage by rain or water accumulation. Reroute surface water runoff away from excavated areas. Do not allow water to accumulate in excavations. Do not use excavated trenches as temporary drainage ditches.

E. Dispose of water removed by dewatering in accordance with Section 312320 “Water Treatment and Disposal”.

3.3 CONTROLLED BLASTING

A. Do not begin blasting until the following conditions have been met:
   1. Required submittals specified herein have been made and the Designer and Company have reviewed and accepted the submittals.
   2. Required pre-construction inspections as specified herein and in Company’s Environmental Protection Plan and Permits have been completed.
   3. Required instrumentation as specified herein and in accordance with Section 310913 “Geotechnical Instrumentation and Monitoring” has been installed and baselined.

B. Install flyrock control measures to protect instrumentation, utilities, personnel, the work, and equipment from flyrock.

C. Perform controlled blasting in accordance with approved submittals, using effective smoothwall blasting, line-drilling measures, or channel drilling measures as required.

D. Use controlled blasting techniques and perform blasting without damaging adjacent structures, property, existing pipeline or site improvements including temporary and permanent excavation support systems.

E. Comply with thresholds stated in Section 310913 "Geotechnical Instrumentation and Monitoring" or lower if determined necessary to prevent damage to walls or pipeline by the Contractor's Blasting Consultant's analysis.

F. Perform blasting without weakening the bearing capacity of rock subgrade or increasing its hydraulic conductivity and with the least-practicable disturbance to rock to remain.

G. Scale and stabilize all rock on the cut face that is loose, hanging, or that creates a potentially dangerous condition during or upon completion of the excavation in each round, to the satisfaction of the Blaster-in-Charge and any representatives of the Company or Designer. Do not commence drilling of the next round until this work has been completed.

H. Post-Blast Inspection: After a blast has been fired, make a careful inspection of the blast area. The inspection should be completed by the Blaster-in-Charge and one assistant under his/her direct supervision. Determine whether there are any indications that misfires might have occurred or whether the blast created any other imminent dangers such as unstable ground conditions. If misfires or other dangerous conditions are found, immediately notify the Company and Designer, secure the area and properly correct all hazards before any other work is allowed in the affected area. Do not give the all clear signal, allowing other work to resume in the area, until affected blast sites are clear of all hazards. The Company or Designer may be present for this inspection.

I. If Contractor proposes modification to blasting plan, re-submit all associated submittals for approval.

J. Blasting operations may be temporarily suspended by the Company or Designer for any of the following reasons:
   1. Contractor's safety precautions are inadequate.
   2. Air-overpressure and ground vibration levels exceed specified response levels.
   3. Excavation by drill and blast results in excessive overbreak or over-excavation.
   4. Blasting endangers the stability of or causes damage to adjacent structures, utilities or support-of-excavation systems.
   5. The results of the blasting, in the sole opinion of the Company or Designer, are not satisfactory.

K. In the event of a suspension, do not resume blasting operations until the Company and Designer have reviewed and accepted the Contractor's revised blasting plan with modifications correcting the conditions causing the suspension.

3.4 EXCAVATION, GENERAL

A. Unclassified Excavation: Excavate to subgrade elevations regardless of the character of surface and subsurface conditions encountered. Unclassified excavated materials may include rock, soil materials, and obstructions.
   1. If excavated materials intended for fill and backfill include unsatisfactory soil materials and rock, replace with satisfactory soil materials.
   2. Remove rock to lines and grades indicated on Agreement Drawings to permit installation of permanent construction without exceeding the following dimensions:
      a. 24 inches outside of concrete forms other than at footings.
      b. 12 inches outside of concrete forms at footings.
      c. 12 inches outside of minimum required dimensions of concrete cast against grade.
      d. Outside dimensions of concrete walls indicated to be cast against rock without forms or exterior waterproofing treatments.
      e. 6 inches beneath bottom of concrete slabs-on-grade.
      f. 6 inches beneath pipe in trenches, and the greater of 24 inches wider than pipe or 42 inches wide.

3.5 EXCAVATION FOR STRUCTURES

A. Excavate to indicated elevations and dimensions within a tolerance of plus or minus 1 inch in soil and 6 inches in rock. If applicable, extend excavations a sufficient distance from structures for placing and removing concrete formwork, for installing services and other construction, and for inspections.

B. Excavation for Portal and Shaft: Do not disturb bottom of excavation. Trim bottoms to required lines and grades to leave solid base to receive other work. Do not damage support-of-excavation elements during excavation.

C. Excavations for Footings and Foundations: Do not disturb bottom of excavation. Trim bottoms to required lines and grades to leave solid base to receive other work.

D. Excavation for Underground Tanks, Basins, and Mechanical or Electrical Utility Structures: Excavate to elevations and dimensions indicated within a tolerance of plus or minus 1 inch in soil and 6 inches in rock. Do not disturb bottom of excavations intended as bearing surfaces.

E. Excavations at Edges of Tree- and Plant-Protection Zones:
   1. Excavate by hand to indicated lines, cross sections, elevations, and subgrades. Use narrow-tine spading forks to comb soil and expose roots. Do not break, tear, or chop exposed roots. Do not use mechanical equipment that rips, tears, or pulls roots.
   2. Cut and protect roots according to requirements Company's Environmental Protection Plan and Permits.

3.6 EXCAVATION FOR WALKS AND PAVEMENTS

A. Excavate surfaces under walks and pavements to indicated lines, cross sections, elevations, and subgrades.

3.7 EXCAVATION FOR UTILITY TRENCHES

A. Excavate trenches to indicated gradients, lines, depths, and elevations.
   1. Beyond building perimeter, excavate trenches to allow installation of top of pipe below frost line.

B. Excavate trenches to uniform widths to provide the following clearance on each side of pipe or conduit. Excavate trench walls vertically from trench bottom to 12 inches higher than top of pipe or conduit unless otherwise indicated.
   1. Clearance: 12 inches each side of pipe or conduit unless indicated otherwise in Agreement Drawings.
   2. For oil pipeline, do not excavate trench wider than 39 inches.

C. Trench Bottoms: Excavate trenches 6-inches deeper than bottom of pipe and conduit elevations to allow for bedding course. Hand-excavate deeper for bells of pipe.
   1. Excavate trenches 6-inches deeper than elevation required in rock or other unyielding bearing material to allow for bedding course.

D. Trenches in Tree- and Plant-Protection Zones:
   1. Hand-excavate to indicated lines, cross sections, elevations, and subgrades. Use narrow-tine spading forks to comb soil and expose roots. Do not break, tear, or chop exposed roots. Do not use mechanical equipment that rips, tears, or pulls roots.
   2. Do not cut main lateral roots or taproots; cut only smaller roots that interfere with installation of utilities.
   3. Cut and protect roots according to requirements in Company's Environmental Protection Plan and Permits.

3.8 UNAUTHORIZED EXCAVATION

A. Fill unauthorized excavation under foundations or wall footings by:
   1. Extending bottom elevation of concrete foundation or footing to excavation bottom, without altering top elevation; or,
   2. Placing and compacting Structural Fill in accordance with the requirements herein.

B. Fill unauthorized excavations under other construction, pipe, or conduit by placing and compacting Granular Fill in accordance with the requirements herein.

3.9 STORAGE OF SOIL MATERIALS

A. Stockpile borrow soil materials and excavated satisfactory soil materials without intermixing. Place, grade, and shape stockpiles to drain surface water. Cover to prevent windblown dust.

B. Stockpile soil materials away from edge of excavations. Do not store within drip line of remaining trees. Do not store near existing structures or foundations.

3.10 BACKFILL

A. Place and compact backfill in excavations promptly, but not before completing the following:

1. Construction below finish grade including, where applicable, subdrainage, dampproofing, waterproofing, and perimeter insulation.
2. Surveying locations of underground utilities for Record Documents.
3. Testing and inspecting underground utilities.
4. Removing concrete formwork.
5. Removing trash and debris.
6. Removing temporary shoring and bracing, and sheeting.
7. Installing permanent or temporary horizontal bracing on horizontally supported walls.
8. Completing inspection and testing in accordance with approved ITP.

B. Place backfill on subgrades free of mud, frost, snow, or ice.

3.11 UTILITY TRENCH BACKFILL

A. Place backfill on subgrades free of mud, frost, snow, or ice.

B. Place and compact bedding course on trench bottoms and where indicated on Agreement Drawings. Shape bedding course to provide continuous support for bells, joints, and barrels of pipes and for joints, fittings, and bodies of conduits.

C. Trenches Under Footings: Backfill trenches excavated under footings and within 18 inches of bottom of footings with satisfactory soil; fill with structural concrete to elevation of bottom of footings. Structural concrete is specified in Section 033100 "Structural Concrete Materials".

D. Trenches Under Roadways: Provide 4-inch thick, concrete-base slab support for piping or conduit less than 30 inches below surface of roadways. After installing and testing, completely encase piping or conduit in a minimum of 4 inches of concrete before backfilling or placing roadway subbase course. Concrete is specified in Section 033100 "Structural Concrete Materials".

E. Backfill voids with satisfactory soil while removing shoring and bracing.

F. Place and compact initial backfill of subbase material, free of particles larger than 1 inch in any dimension, to a height of 12 inches over the pipe or conduit.
   1. Carefully compact initial backfill under pipe haunches and compact evenly up on both sides and along the full length of piping or conduit to avoid damage or displacement of piping or conduit. Coordinate backfilling with utilities testing.

G. Install warning tape directly above utilities, at depths in accordance with MDOT and Company requirements.

H. For initial and final backfill for stormwater culverts, use relatively impervious material, such as clay. When impervious material is not readily available, pit-run, granular backfill may be used for all but the outer 1.0 m (40 in.) at both ends of the culvert, for which only impervious material shall be used.

3.12 SOIL FILL

A. Plow, scarify, bench, or break up sloped surfaces steeper than 1 vertical to 4 horizontal so fill material will bond with existing material.

B. Place and compact fill material in layers to required elevations as follows unless indicated otherwise on Agreement Drawings:
   1. Under grass and planted areas, use a minimum of 2-feet of landscape fill for the uppermost fill. Use General Fill and Backfill below.
   2. Under gravel roads and walkways, use General Fill and Backfill.
   3. Under steps and ramps, use Structural Fill.
   4. Under building slabs, use Structural Fill.
   5. Under footings and foundations, use Structural Fill.

C. Place soil fill on subgrades free of mud, frost, snow, or ice.

D. Place granular material using methods that do not lead to segregation or degradation. If segregation during spreading occurs, remove and replace the affected portion of the layer.

3.13 SOIL MOISTURE CONTROL

A. Uniformly moisten or aerate subgrade and each subsequent fill or backfill soil layer before compaction to within 2 percent of optimum moisture content, or as approved by Designer.

B. Do not place backfill or fill soil material on surfaces that are muddy, frozen, or contain frost or ice.

C. Remove and replace, or scarify and air dry, otherwise satisfactory soil material that exceeds optimum moisture content by 2 percent and is too wet to compact to specified dry unit weight.

3.14 COMPACTION OF SOIL BACKFILLS AND FILLS

A. Use compaction equipment capable of obtaining the material dry unit weights specified herein.

B. Shape and roll backfill or fill to achieve an even and uniformly compacted layer before adding the next layer of material.

C. In areas not accessible to rolling equipment, compact to the specified density with mechanical tampers.

D. Place backfill and fill soil materials in layers not more than 6 inches in loose depth for material compacted by heavy compaction equipment, and not more than 4 inches in loose depth for material compacted by hand-operated tampers, unless thicker layers are approved by the Designer.

E. Place backfill and fill soil materials evenly on all sides of structures to required elevations, and uniformly along the full length of each structure.

F. Compact soil materials to not less than the following percentages of maximum dry unit weight according to ASTM D1557:
   1. Under structures, building slabs, steps, gravel roads and walkways, scarify and recompact top 12 inches of existing subgrade and each layer of backfill or fill soil material at 95 percent.
   2. Under walkways, scarify and recompact top 6 inches below subgrade and compact each layer of backfill or fill soil material at 90 percent.
   3. Under turf or unpaved areas, scarify and recompact top 6 inches below subgrade and compact each layer of backfill or fill soil material at 85 percent.
   4. For utility trenches, compact each layer of initial and final backfill soil material at 85 percent.

3.15 GRADING

A. General: Uniformly grade areas to a smooth surface, free of irregular surface changes. Comply with compaction requirements and grade to cross sections, lines, and elevations indicated on Agreement Drawings.
   1. Provide a smooth transition between adjacent existing grades and new grades.
   2. Cut out soft spots, fill low spots, and trim high spots to comply with required surface tolerances.

B. Site Rough Grading: Slope grades to direct water away from buildings and to prevent ponding. Finish subgrades to required elevations within the following tolerances:
   1. Turf or Unpaved Areas: Plus or minus 1 inch.
   2. Walks: Plus or minus 1 inch.
   3. Pavements: Plus or minus 1/2 inch.

C. Grading Inside Building Lines: Finish subgrade to a tolerance of 1/2 inch when tested with a 10-foot straightedge.

3.16 SUBSURFACE DRAINAGE

A. Subdrainage Pipe: Specified in Section 334000 “Storm Drainage Systems”.

B. Subsurface Drain: Place geotextile blanket around perimeter of subdrainage trench. Place a 6-inch course of filter material on subsurface drainage geotextile to support subdrainage pipe. Encase subdrainage pipe in a minimum of 12 inches of filter material, placed in compacted layers 6 inches thick, and wrap in geotextile blanket, overlapping sides and ends at least 6 inches.
   1. Compact each filter material layer to 85 percent of maximum dry unit weight according to ASTM D1557.

C. Drainage Backfill: Place and compact filter material over subsurface drain, in width indicated, to within 12 inches of final subgrade, in compacted layers 6 inches thick. Overlay drainage backfill with one layer of geotextile blanket, overlapping sides and ends at least 6 inches.
   1. Compact each filter material layer to 85 percent of maximum dry unit weight according to ASTM D1557.

3.17 SUBBASE AND BASE COURSES UNDER PAVEMENTS AND WALKS

A. Refer to requirements in Section 321100 “Base and Aggregate Surface Courses”.

3.18 DRAINAGE COURSE UNDER CONCRETE SLABS-ON-GRADE

A. Place drainage course on subgrades free of mud, frost, snow, or ice.

B. On prepared subgrade, place and compact drainage course under cast-in-place concrete slabs-on-grade as follows:
   1. Install geotextile blanket on prepared subgrade according to manufacturer's written instructions, overlapping sides and ends.
   2. Place drainage course 6 inches or less in compacted thickness in a single layer.
   3. Place drainage course that exceeds 6 inches in compacted thickness in layers of equal thickness, with no compacted layer more than 6 inches thick or less than 3 inches thick.
   4. Compact each layer of drainage course to required cross sections and thicknesses to not less than 95 percent of maximum dry unit weight according to ASTM D1557.

3.19 PROTECTION

A. Protecting Graded Areas: Protect newly graded areas from traffic, freezing, and erosion. Keep free of trash and debris.

B. Repair and reestablish grades to specified tolerances where completed or partially completed surfaces become eroded, rutted, settled, or where they lose compaction due to subsequent construction operations or weather conditions. Scarify or remove and replace soil material to depth as directed by Designer or Company; reshape and recompact.

C. Where settling occurs before the correction period as defined in the Agreement and Exhibits elapses, remove finished surfacing, backfill with additional soil material, compact, and reconstruct surfacing. Restore appearance, quality, and condition of finished surfacing to match adjacent work, and eliminate evidence of restoration to greatest extent possible.

3.20 DISPOSAL OF SURPLUS AND WASTE MATERIALS

A. Dispose of surplus and waste materials in accordance with Section 312326 “Reuse and Disposal of Excavated Material”.

3.21 FIELD QUALITY CONTROL

A. At a minimum, include the following items in the Inspection and Test Plan:
   1. Surveillance:
      a. Proper fill placement and compaction including lift placement thickness and in-situ testing.
      b. Calibration of equipment used for survey and earthwork testing.
   2. Review:
      a. Not used.

3. Verification:
   a. Resilient modulus test results.
   b. Subgrade bearing capacity test results.
   c. Flowable fill test results.
   d. Proper storage of explosives and blasting materials.
4. Witness Point:
   a. Not used.
5. Hold Point:
   a. Blasting submittals submitted and approved.
   b. Blasting preconstruction inspection completed.
   c. Blasting control measures installed.
   d. Post-blast inspection.
   e. Instrumentation and monitoring equipment installed, baselined and protected.
   f. Subgrade inspection.
   g. Subbase preparation.
   h. Final grades.
   i. In-situ Moisture Content and Density test results prior to placement of next lift of fill.

B. Special Inspector: Engage and provide access for the Special Inspector to perform independent quality control activities as follows:
   1. Determine prior to placement of fill that site has been prepared in compliance with requirements.
   2. Determine that fill material classification and maximum lift thickness comply with requirements.
   3. Determine, during placement and compaction, that in-place density of compacted fill complies with requirements.
   4. Determine, during placement, that in-place density and strength of flowable fill complies with requirements.

C. Notify and allow Special Inspector to inspect and test subgrades and each fill or backfill layer. Proceed with subsequent earth moving only after test results for previously completed work comply with requirements.

D. Footing Subgrade: At footing subgrades, perform at least one set of five field tests (Dynamic Cone Penetrometer to ASTM D6951 or approved alternative) of each soil stratum to verify design bearing capacities. Report California Bearing Ratio (CBR). Use published correlations applicable to the equipment used and soil type tested and as approved by Designer in Inspection and Test Plan. All five tests are required to meet the minimum design value for acceptance. Not required for rock subgrades. Subsequent verification and approval of other footing subgrades may be based on a visual comparison of subgrade with tested subgrade.

E. Special Inspector will test compaction of soils in place according to ASTM D1556, ASTM D2167, ASTM D6938, and ASTM D2937, as applicable. Tests will be performed at the following locations and frequencies:
   1. Gravel Roads, Walkways and Building Slab Areas: At subgrade and at each compacted fill and backfill layer, at least one test for every 2000 sq. ft. or less of paved area or building slab, but in no case fewer than three tests for each area.
   2. Foundation Wall Backfill: At each compacted backfill layer, at least one test for every 100 feet or less of wall length, but no fewer than two tests.

3. Trench Backfill: At each compacted initial and final backfill layer, at least one test for every 100 feet or less of trench length, but no fewer than two tests.
4. Mackinaw Station Portal and Ramp Backfill: At each compacted fill and backfill layer, at least one test for every 2000 sq. ft. or less of fill area, but in no case fewer than three tests.

F. When Special Inspector reports that subgrades, fills, or backfills have not achieved degree of compaction specified, scarify and moisten or aerate, or remove and replace soil materials to depth required; recompact and retest until specified compaction is obtained.

END OF SECTION 31 20 00

SECTION 315600 – DIAPHRAGM WALLS

PART 1 - GENERAL

1.1 SUMMARY

A. Section includes furnishing of all labor, materials, tools and equipment, and performing all operations necessary for construction of concrete diaphragm walls using clamshell or hydromill techniques or other approved alternative, at the locations and to the dimensions indicated on the Agreement Drawings. Diaphragm walls are intended to provide a temporary, and in some areas permanent, watertight support of excavation for the North Straits Shaft and part of the Mackinaw Station Portal.

1. Diaphragm wall is designed to provide a watertight soil/rock retention system in both the temporary and permanent condition. The diaphragm wall has a 100 year design life.
2. Minimum criteria and minimum design requirements for the diaphragm wall: To provide temporary and permanent lateral load support, to provide a watertight wall to minimize groundwater drawdowns and porewater changes outside the diaphragm wall and facilitate a dry excavation, and to minimize impacts on adjacent structures and utilities as shown on the Agreement Drawings and described herein. These criteria are intended to serve as minimum requirements as well as a guide to the Contractor.
3. Construct diaphragm wall to maintain the minimum shaft dimensions indicated on the Agreement Drawings.
4. Design panel joints to provide positive groundwater cutoff.
5. Minimum diaphragm wall compression ring thickness is shown on the Agreement Drawings.

B. Related Requirements:

1. Section 033000 “Cast-In-Place Concrete” for steel and glass fiber reinforced polymer (GFRP) reinforcement requirements.
2. Section 033100 “Structural Concrete Materials” for concrete mix designs and required concrete strengths.
3. Section 051200 “Structural Steel Framing” for requirements related to steel soldier beams.
4. Section 310913 “Geotechnical Instrumentation and Monitoring” for instrumentation and monitoring including response levels.
5. Section 312000 “Earthwork/Excavation and Backfill” for excavation of the portal/shaft and backfilling requirements.
6. Section 312319 “Dewatering” for dewatering performance requirements.
7. Section 312500 “Erosion and Sedimentation Controls”.
8. Section 315000 “Excavation Support and Protection” for general excavation support requirements including temporary bracing and Digital Excavation Monitoring and Documentation System.
9. Section 315100 “Ground Anchors” for ground anchor (tieback) requirements.
10. Section 318200 “Permeation Grouting” for permeation grouting performance requirements.

1.2 DEFINITIONS

A. Break-ins and Break-outs: Diaphragm wall/shaft penetrations for tunnel/adit connections out of an into the shaft.

B. Concrete Diaphragm Wall: A reinforced concrete wall constructed by the slurry trench method, also referred to as “slurry wall” reinforced with steel or glass fiber reinforced polymer (GFRP) reinforcement cages.

C. Concrete Consistence: Relative mobility, or ability of freshly mixed concrete to flow. An indication of workability.

D. Concrete Workability: The property of freshly mixed concrete which determines the ease with which it can be mixed, poured, compacted, and finished.

E. Contaminated Support Fluid: Support fluid originally mixed and used to support the diaphragm wall excavation but no longer meets the criteria indicated.

F. Damp Patch: When touched, a damp patch may leave a slight film of moisture on the hand, but no droplets of water or greater degrees of wetness are left on the hand. On a concrete surface a damp patch is discernible from a darkening of the color of the concrete.

G. Design Line: Theoretical inside face of diaphragm wall.

H. End Stop: A vertical form used to create a uniform construction joint between adjacent diaphragm wall panels.

I. Filter Cake: Formation of a cake of filtered material, such as bentonite and excavated soil from a suspension, built up in the transition zone to a permeable medium, by water drainage due to pressure.

J. Primary Panel: Diaphragm wall panel excavated through soil using one or more passes of the diaphragm wall machine with no adjacent panels.

K. Ring Beam or Capping Beam: Cast-in-place reinforced concrete circumferential beam or some other similar element constructed inside and against the diaphragm wall before and after construction of tunnel break-ins and break-outs, intended to resist ground movement/loads including water pressure integrally with the diaphragm wall. Capping beam is located at top of diaphragm wall. Obtain the integral connection of the capping beam with diaphragm wall through the use of reinforcing steel, dowels, couplers, grouting or combination thereof.

L. Flowing Water: Water quantity that exceeds that defined for seeping water.

M. Secondary Panel (Closing Panel): Diaphragm wall panel excavated using one or more passes of the diaphragm wall machine between two primary panels.

N. Seeping Water: Patches or beads of moisture with no discernable interruption of water flow when a finger is dragged across the wall surface through the wet area.

O. Diaphragm Wall Panel: One section of a completed diaphragm wall, constructed as a single concrete pour. One panel may be excavated using one or more passes of the excavation equipment.

P. Diaphragm Wall Spoil: Soils, support fluid, concrete, and other materials generated during diaphragm wall excavation and concreting.

Q. Tremie Concrete: Concrete placed by means of tremie pipe equipment, for depositing concrete under water or support fluid, the discharge end of the pipe being kept submerged in the freshly deposited concrete so that the concrete-water or concrete-support fluid interface is not disturbed.

R. Waterstop: Polyvinyl chloride (PVC) element with high breaking elongation installed within the vertical joints between diaphragm wall panels to seal the joint against water ingress.

S. Watertight: The diaphragm wall is considered watertight when the leakage criteria specified herein are met.

1.3 REFERENCES

A. American Concrete Institute (ACI):
1. ACI 211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete.
2. ACI 211.4R Guide for Selecting Proportions for High Strength Concrete with Portland Cement Fly Ash.
3. ACI 214 Guide to Evaluation of Strength Test Results of Concrete.
4. ACI 222.3R Guide to Design and Construction Practices to Mitigate Corrosion of Reinforcement in Concrete Structures.
5. ACI 301 Specifications for Structural Concrete.
6. ACI 304 Measuring, Mixing, Transporting and Placing Concrete.
7. ACI 304.2R Guide to Placing Concrete by Pumping Methods.
8. ACI 308R Guide to External Curing of Concrete.
9. ACI 318 Building Code Requirements for Structural Concrete and Commentary.

B. The American Association of State Highway Transportation Officials (AASHTO):
1. AASHTO R81-17 Standard Practice for Static Segregation of Hardened Self-Consolidating Concrete (SCC) Cylinders.

C. American Petroleum Institute (API):
1. SPEC 13A Specification for Drilling Fluid Materials.
2. RP 13B-1 Recommended Practice for Field Testing Water-Based Drilling Fluids.

D. ASTM International (ASTM):
1. ASTM A36 Standard Specification for Carbon Structural Steel.
2. ASTM A53 Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless.
3. ASTM A615 Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement.
4. ASTM A706/A706M Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement.
5. ASTM A992 Standard Specification for Structural Steel Shapes.

6. ASTM C31/C31M Standard Practice for Making and Curing Concrete Test Specimens in the Field.
7. ASTM C33/C33M Standard Specification for Concrete Aggregates.
8. ASTM C39/C39M Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.
9. ASTM C42 Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete.
10. C88/C88M Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate.
11. ASTM C94/C94M Standard Specification for Ready-Mixed Concrete.
12. ASTM C150/C150M Standard Specification for Portland Cement.
13. ASTM C232/C232M Standard Test Method for Bleeding of Concrete.
14. ASTM C1611/C1611M Standard Test Method for Slump Flow of Self-Consolidating Concrete.
15. ASTM D1785 Standard Specification for Poly Vinyl Chloride (PVC) Plastic Pipe, Schedules 40, 80 and 120.
16. ASTM D4380 Standard Test Method for Density of Bentonitic Slurries.
17. ASTM D4381 Standard Test Method for Sand Content by Volume of Bentonitic Slurries.
18. ASTM D6910 Standard Test Method for Marsh Funnel Viscosity of Clay Construction Slurries.

E. European Federation of Foundation Contractors / Deep Foundations Institute (EFFC/DFI):
1. Guide to Tremie Concrete for Deep Foundations. 2nd Ed. 2018.

1.4 PREINSTALLATION MEETINGS

A. Conduct pre-installation meeting at project site, attended at a minimum by representatives from the Company, Contractor, Diaphragm Wall Subcontractor, if applicable, Designer, and Quality Personnel including Special Inspector as applicable.

B. Conduct preinstallation meeting after all submittals required to perform the work have been approved, and at least 48 hours prior to starting a new operation.

C. At a minimum, review the following:
1. Health, safety and environmental hazards.
2. Emergency plans and response protocols.
3. Material Safety Data Sheets (MSDS) sheets.
4. Specifications including field quality control (QC) requirements.
5. Approved submittals including Inspection and Test Plan.
6. Reporting requirements.
7. Contractor’s preparation.
8. Key personnel involved with the work.
9. Contingency plans.

1.5 ACTION SUBMITTALS

A. Product Data: Submit for all proposed products, including:
1. Copies of manufacturer’s specifications for support fluid, including copies of laboratory test reports and other data as may be required to show compliance with these specifications.

2. Complete specifications for all equipment proposed to be used for construction.
3. Copies of certified mill reports describing the chemical and physical properties of steel reinforcement.
4. Product data for glass fiber reinforced materials in accordance with requirements for Glass Fiber Reinforced Polymer Reinforcing in Section 033000 "Cast-In-Place Concrete".
5. Manufacturer's technical information and test data for threaded inserts, couplers and other embedded items.

B. Shop Drawings: Submit for guide wall, diaphragm wall, capping beam, initial support, ground improvement or stabilization measures and groundwater cutoff, including:
   1. Detailed construction sequence for diaphragm wall construction, including site preparation, guide wall, diaphragm wall panel installation, ground stabilization and groundwater cutoff.
   2. Drawings for guide wall showing:
      a. Setting out information, including survey control points used.
      b. Concrete formwork.
      c. Details and dimensions of reinforcing steel.
      d. Excavation protection beside and above adjacent utilities or substructures.
      e. Construction tolerances.
   3. Drawings for diaphragm wall panels, including the following details:
      a. Layout drawings showing proposed panel location, panel identification number, lengths, depths, and end stops if applicable.
      b. Details of reinforcing steel, including reinforcement sizes and spacing, couplers, product data, provision for protection against contamination and corrosion while stored on site, stiffening, lifting, splicing and positioning reinforcement cages within tolerances specified herein.
      c. Details of plates, sleeves, pipes, dowels, and other embedded items, including tremie grout pipes and casings for instrumentation to be installed within wall panels.
      d. Details of keyways, recesses, and block-outs, including locations and block-out material type. Details of removal procedures for block-outs.
      e. End Stop Details: Materials, size, length, and installation and removal procedures.
      f. Waterstop Details: Material, size, length, and installation and removal procedures.
      g. Details for spacers for providing required concrete cover to reinforcement cages, and how they will be affixed to the panel reinforcement.
      h. Fall protection measures, embedded post, etc. showing sufficient clearance to access and read structural and/or geotechnical instrumentation.
      i. Calculations prepared by Diaphragm Wall Contractor's engineer with regard to density/head of the support fluid sufficient to maintain the stability of the trench in the anticipated ground conditions and for anticipated maximum time the panels will be open. Perform this analysis for the proposed panel dimensions. Include an analysis showing that the composition of the support fluid is compatible with the groundwater constituents to be encountered.

C. Samples:
   1. Samples of all field QC reports.

D. Diaphragm Wall Work Plan: Submit written work plan for the overall construction sequence and the following:
   1. Site plan showing the arrangement of plant and equipment associated with diaphragm wall construction, stockpiles, staging areas, containment areas, etc. as needed to perform work,

including on-site traffic routes and access route for concrete trucks to panel or concrete pump.

2. Location and concepts for support fluid preparation, site distribution, reclamation, and disposal, including back-up provisions.
3. Location and methods of monitoring and testing support fluid to comply with specified requirements.
4. Methods of diaphragm wall excavation and estimated rates of excavation for each material type expected to be excavated. Include description of methods of pre-trenching to clear debris prior to installing guide walls.
5. Method of excavating boulders, or other obstructions in diaphragm wall trench.
6. Method for installing wall panels within specified positional tolerances, method of monitoring plumbness and deviation of wall panels during excavation, and details of proposed corrective measures to be implemented if necessary.
7. Method for maintaining the stability of diaphragm wall trenches during excavation.
8. Methods for checking and proving the cleanliness of trench bottoms prior to placement of reinforcement, installation of end stops and concrete placement.
9. Method for ultrasonic surveying, or equivalent, of panels prior to placement of reinforcement.
10. Method of forming and cleaning joints between adjacent wall panels to provide watertight joints, verifying joints are clean, polystyrene foam block-outs (if used) are completely removed, and ensuring waterstops are in place.
11. Methods of installing and securing end stops, installing, splicing and securing reinforcement cages, and method for removing end stops. Methods to confirm correct position of reinforcement cages.
12. Method of concrete placement and/or pumping (by tremie).
13. Methods for pumping, processing, and disposal of displaced support fluid.
14. Methods for providing a suitable plug in the tremie pipe prior to discharging concrete into each panel. Methods employed to maintain positive concrete head and to verify minimum embedment of tremie pipe in concrete throughout concrete placement.
15. Methods to protect personnel, the public and the surrounding property from hazards inherent in the operations, including leakage and spillage of support fluid, falls into open guide trenches or excavated wall panels, and methods of lifting and setting reinforcement cages, tremie pipes, end stops and de-sanding pipes.
16. Method of monitoring and maintaining support fluid level in excavations left open overnight or over an extended period of time.
17. Method of maintaining stability of excavated trenches in case of sudden loss of support fluid.
18. Measures for preventing support fluid from entering into utility facilities.
19. Approach to ensuring that surcharge pressures from equipment and materials in the vicinity of support-fluid-filled panels do not exceed the allowable pressures assumed in Diaphragm Wall Contractor's trench stability analysis.
20. Method of installing and maintaining sleeves embedded in the diaphragm wall straight and vertical prior to, during and after concrete placement to allow for instrumentation and grout sleeves in and below the wall.
21. Method of protecting support fluid operations, including storage, handling, and disposal, during all seasons.
22. Locations of truck cleaning stations and methods of ensuring that haul trucks are clean and that no spillage of excavated material from haul trucks occur on existing streets.
23. Method of hauling and disposing of the excavated materials and support fluid to an approved disposal site.

24. Method of cleaning the bottom of a panel in the event that side collapse of the trench occurs while reinforcing steel is either partially or fully installed.
25. Methods proposed for monitoring, prevention and/or re-treatment of subsurface strata to prevent significant ground loss, running or flowing ground conditions, and detailed contingency measures for:
    a. Collapse of the excavated diaphragm wall panel, including procedures for re-excavation.
    b. Open joints between two diaphragm wall panels during shaft excavation and dewatering.
    c. Honeycombed or otherwise substandard concrete during shaft excavation and dewatering.
    d. Unacceptable water inflows up through the excavation subgrade.
26. Identification of panels targeted for local excavation to expose outside face of panel over top 10 feet, including methods for forming safe excavation, cleaning and inspecting section of panel, and backfilling.

E. Design Mixes:
1. Concrete mix design(s) in accordance with Section 033100 "Structural Concrete Materials" including results of concrete mix trials as specified herein.
2. Support Fluid Design: If a support fluid other than bentonite, such as Polymer, is proposed include documentation of the successful use of the support fluid in similar operations, with similar ground conditions.

F. Inspection and Test Plan (ITP): Develop for each definable feature of work in accordance with the Contractor's approved work plan. Include in the ITP as a minimum:
1. Survey control.
2. Requirements to verify calibration and certification of equipment.
3. Required testing and inspections and acceptance criteria.
4. Surveillance, review, verification, witness points and hold points.
5. Notification requirements.
6. Which parties are present.

G. Corrective Action Plan:
1. Repair procedures and materials for corrective measures to remediate or replace non-conforming panels to specified requirements. Non-conforming panels are panels not meeting the design requirements indicated on the Agreement Drawings or specified herein.
2. Provide associated structural design calculations signed and sealed by Diaphragm Wall Contractor's Registered Professional Engineer licensed in the State of Michigan to demonstrate that the repaired panel is structurally acceptable.
3. Proposed corrective actions to seal leaks in diaphragm wall. These corrective actions include, but not be limited to, sealing leaks in or between wall panels, and grouting soils or rock behind wall panels.
4. Corrective actions for common deficiencies can be pre-emptively submitted for approval. Each use of these corrective actions requires approval from the Designer and Company before implementation, unless otherwise agreed with Designer and Company.

1.6 INFORMATIONAL SUBMITTALS

A. Qualification Data: Resumes or documentation of experience for the following individuals or companies identified in the Quality Assurance requirements to demonstrate the experience requirements are met:
   1. Diaphragm Wall Contractor.
   2. Project Superintendent.
   3. Hydromill and clamshell operator(s).
   4. Diaphragm Wall Contractor's Engineer.
   5. Special Inspector.
   6. Other Contractor-Appointed Quality Personnel.

B. Minutes of Preinstallation Meeting: Submit to Company and Designer for information within 48 hours of meeting.

C. Record Drawings:
   1. Provide the following in 2D PDF drawings and spatially referenced in 3D CAD. Call out any deviations of as-built conditions from design:
      a. Panel identification.
      b. Panel position (plan location and plumbness), dimensions of the excavation, position and dimensions of the guide walls.
      c. Details and locations of any instrumentation installed in the panels.
      d. Steel reinforcement, box-outs, cut-outs, couplers, threaded inserts, sleeves, or other embedded items.
      e. Locations and nature of leaks, with temporal data.
      f. Locations and nature of any remedial works.
      g. Locations and extent of patched areas in concrete.
   2. Provide in electronic format dates, times and quantities of panel excavation; end stop, and reinforcement placement; tremie concrete placement; and end stop removal.

D. Field Quality-Control Reports:
   1. Field quality-control data and monitoring data in a visually intuitive way. Provide all data in electronic format, and spatially referenced wherever applicable. Also submit original records where data is collected manually. Incorporate diaphragm wall installation data within Digital Excavation Monitoring and Documentation System wherever possible as specified in Section 315000 "Excavation Support and Protection".
   2. Excavation Report: Excavation records immediately after each panel excavation has been completed. Include in report panel identification, dates and time of excavation, plan, location and dimensions of excavation (including deviations from plan location), elevations of guide walls and top and bottom of panel, trench bottom inspection, continuous descriptions and elevations of actual soils and rock encountered based on logging of cuttings and review of rig telemetry data, and all excavation problems encountered.
   3. Verticality Verification Report: Submit immediately after excavation of each panel is completed. Report to include actual versus design plan position and verticality for each excavation pass, including full ultrasonic survey (Koden or equivalent) results.
   4. Support Fluid Report: Submit daily. Report to include results of all test specified herein.
   5. Reinforcement Placement Report: Submit as-built records after each panel is completed. Include pre-installation inspection report for reinforcement fabrication and placement, including locations of splices, block-outs, embedments, monitoring instruments, guides and spacers. Include description of deviations from Shop Drawings. Include waterstop placement details.

6. Concrete Placement Report: Submit records after each concrete placement. Report to include time-synchronized tremie pipe elevations, top of concrete elevations, placement location, theoretical concrete volume, actual concrete volume, placement rate, and sampling schedule. Record actual concrete volume supplied to panel continuously, and measure top of concrete elevation at not greater than 10-foot vertical intervals.
7. Concrete Testing Report: Report to include results of consistence, stability and strength testing as identified herein.
8. Panel Installation Schedule Report: Submit weekly panel installation progress detailing planned schedule versus actual progress.
9. Panel External Face Report: For panels where local excavation is carried out to facilitate inspection of top section of outside face of panel, submit a report including detailed photographs, description and measurement of filter cake thickness, and observations of quality of cover-zone concrete including any instances of mattressing, shadowing, bleed channels or other defects.

1.7 QUALITY ASSURANCE

A. Qualifications:
1. Perform all work under these specifications using a Diaphragm Wall Contractor experienced with diaphragm wall methods of construction and with a minimum of ten years of direct experience on three diaphragm wall systems of a similar type as is required for this project.
2. Provide a fulltime project superintendent who has five years of experience and worked on at least two diaphragm wall contracts in similar ground conditions, depths, and using similar equipment as required for this project.
3. Provide hydromill and clamshell operator(s) with a minimum of 3 years' experience with projects of similar size and complexity. If operator does not meet minimum experience requirements, provide evidence of sufficient training and plan for oversight throughout the works.
4. Provide Diaphragm Wall Contractor's Engineer who is a Registered Professional Civil Engineer licensed in the State of Michigan and who has designed and overseen a minimum of 3 diaphragm wall projects of similar size and complexity over the last 10 years.

1.8 PRECONSTRUCTION TESTING

A. Trial Concrete Mixes:
1. Produce a trial batch of at least 4 cubic yards of any proposed diaphragm wall concrete mix. Conduct and report the following tests:
   a. Slump-flow test in accordance with ASTM C1611.
   b. Visual Stability Index in accordance with ASTM C1611.
   c. Slump-flow velocity in accordance with EFFC/DFI Guide to Tremie Concrete for Deep Foundations 2nd Ed.
   d. Workability Retention Test in accordance with EFFC/DFI Guide to Tremie Concrete for Deep Foundations 2nd Ed.
   e. Hardened Visual Stability Index in accordance with AASHTO R81.
   f. Bleeding Test in accordance with ASTM C232.

B. Trial Diaphragm Wall Panel:

1. At each location where diaphragm walls are required construct trial panel excavation of same size and depth as production panels, located at least 10ft clear of production panels, to demonstrate Diaphragm Wall Contractor's construction methods, equipment, standards of workmanship, tolerances, and panel stability.
2. Conduct inspection and testing in accordance with the requirements of Section 3.11 herein and produce excavation report, verticality verification report including ultrasonic (Koden or equivalent) survey, and support fluid report as for production panels.
3. Do not install reinforcement.
4. Backfill trial panel with lean concrete as specified herein and meeting the requirements of Section 313000.
5. If trial panel does not comply with requirements, excavate another until it is accepted.

1.9 DELIVERY, STORAGE, AND HANDLING

A. Store reinforcement cages in a location on-site that permits inspection prior to installation.

B. Lift reinforcement cages in accordance with approved lifting plans.

1.10 FIELD CONDITIONS

A. Anticipated geotechnical conditions are presented in the Geotechnical Baseline Report (GBR) and Geotechnical Data Reports (GDRs).

B. Protection: Protect surfaces of adjacent structures, utilities, pavements, sidewalks, and other facilities to prevent contamination of these surfaces by excavated material, support fluid, and concrete.

C. Vibration Control: Limit vibration due to diaphragm wall construction below response levels as specified in Section 310913 "Geotechnical Instrumentation and Monitoring" and so as to prevent damage to adjacent buildings, structures, utilities, and all other facilities.

D. Working Platform: Install working platform and select commencing surface elevation to allow construction of panels and capping beam to elevations shown on Agreement Drawings.

E. Coordinate panel lengths in terms of trench stability, assessment of ground movements, and in accordance with the Agreement Drawings.

F. Coordinate durations of unfilled panels to maintain trench stability and limit ground movements below response levels as specified in Section 310913 "Geotechnical Instrumentation and Monitoring".

PART 2 - PRODUCTS

2.1 MATERIALS

A. Support Fluid:
1. Select a support fluid type and determine a composition suitable to produce support fluid having the properties and meeting the performance criteria specified below. Adequately account for the ground and groundwater conditions at the site and the specified panel geometry.
2. Provide a support fluid mix design by a Registered Professional Engineer licensed in the State of Michigan having the specified experience in support fluid mix design.
3. Lost Circulation Material (LCM): As determined by the support fluid mix engineer, as necessary, to prevent loss of support fluid through the trench sidewalls and through the bottom of the trench excavations.
4. Water: Clean, potable, and free of impurities detrimental to support fluid, and compatible with the support fluid mix design.
5. Proportions: As determined by the support fluid mix engineer to produce support fluid meeting the performance criteria specified below.
6. The support fluid shall not have adverse effects on the concrete, including but not limited to, setting time, density, and strength.
7. Performance Criteria:
    a. Hydrostatic Head Produced: Sufficient to prevent water and soil inflow to the excavation and maintain trench stability. Maintain required head in panel excavations at all times.
    b. Gel Strength: Sufficient to seal weak and open soil formations.
    c. Stability and Flow: Ensure that the support fluid will remain stable and fluid during excavation and until concreting is completed and flows without gelling under displacement by concrete.
8. If a support fluid other than bentonite is proposed:
    a. Comply with manufacturer's guidance.
    b. Hold meeting with Company and Designer where Contractor and manufacturer's technical representative present proposed support fluid and justify suitability for the application to the Designer.
    c. Provide on-site technical support by support fluid manufacturer for, as a minimum, the first two weeks of diaphragm wall installation at each portal/shaft.
    d. Acceptance by the Company and Designer will be contingent upon demonstration of successful use in similar ground conditions to construct similarly-sized diaphragm wall panels using the same equipment type as proposed herein, and on continuous evaluation of the ability to maintain stability of diaphragm wall trench and ability to provide a clean trench bottom.
9. Bentonite Support Fluid: If bentonite support fluid is proposed:
    a. Use a stable suspension of powdered bentonite in potable water meeting the requirements of API SPEC 13A. Establish hydration time for bentonite support fluid based on the methods used for mixing, agitation, and storage, but a minimum of eight hours before use.
    b. Adjust bentonite support fluid properties, within the limits specified in Table 1, as necessary to suit the specific field conditions encountered in each panel excavation. Changes to the support fluid properties shall be approved by the Designer and noted in the support fluid test reports.

Table 1: Bentonite Support Fluid Properties

Property	Stages		
	Freshly mixed	**Ready for Re-Use**	**Prior to concreting**
Density (pcf)	64.5 to 71	64.5 to 78	64.5 to 72
Viscosity Marsh value (seconds)	32 to 50	32 to 60	32 to 50
Fluid loss (cc in 30 minutes)	<25	<50	<45
pH	7.5 to 11	7.5 to 11	7.5 to 11
Sand content (%)	N/A	N/A	<3

B. Cast-in-Place Concrete:
   1. Guide Walls: In accordance with Diaphragm Wall Contractor's requirements.
   2. Diaphragm Wall Concrete: Per Section 033100 "Structural Concrete Materials".

C. Steel Bar Reinforcement: Per Section 033000 "Cast-In-Place Concrete".

D. Structural Steel Members: Per Section 051200 "Structural Steel Framing".

E. Glass Fiber Reinforced Polymer Reinforcement: Per Section 033000 "Cast-In-Place Concrete".

F. Lean Concrete: 1,000 psi minimum compressive strength at 28 days and with consistence and workability suitable for tremie placement in accordance with requirements of Diaphragm Wall Contractor's mix design for production panels.

G. Centering Devices for Reinforcement Cages: Do not use plastic centering devices.

H. Reservation Casings for Inclinometers: Provide nominal 6-inch internal diameter steel casings of sufficient strength and thickness to prevent distortion on lifting and concrete placement.

I. Bar Couplers: Per Section 033000 "Cast-In-Place Concrete". Reinforcing bar couplers shall be mechanical type.

J. Waterstops: PVC per Section 033000 "Cast-In-Place Concrete". Provide PVC waterstops at all diaphragm wall panel joints.

K. Plywood or foam for blockouts to be approved by the Designer.

2.2 EQUIPMENT

A. Trench Excavation:
   1. Use excavation equipment capable of the following as a minimum:
      a. Removing the anticipated soil and rock types from the diaphragm wall trench and guidewall excavations while maintain excavation stability.
      b. Excavating trench sections to the required widths, depths and lengths and within specified tolerances.
      c. Excavating a trench not less than 20 feet deeper than the deepest panel shown on Agreement Drawings and forming a clean construction joint between adjacent panels.

2. Arrange equipment and equipment operations to permit free vertical passage of support fluid within the trench and to prevent development of suction pressure or excessive turbulence in the liquid support fluid.
3. Take into account that vibrations resulting from diaphragm wall trench excavation operations may cause damage to adjacent improvements or utilities. Control vibrations to avoid such damage. Control the dropping of trench excavating tools, chisels, or chopping bits and other operations, in such a way as not to cause damaging vibrations.

B. Support Fluid Mixing, Storage and Transport:
1. Use equipment that is designed and located to prevent leakage and spillage and produces a stable suspension of bentonite and water along with necessary mechanical agitation.
2. Support Fluid Cleaning: Use equipment that separates the excavated material (such as soil particles, rock fragments and other foreign material) from support fluid before recirculation sufficiently to maintain required in-trench support fluid properties at all times.
3. Support Fluid Storage: Provide storage volume sufficient to enable excavation and concreting to proceed on a continuous basis.
4. Transport support fluid by means of a temporary pipeline or other methods.
5. Dispose of support fluid in compliance with project environmental requirements.

C. After completion of diaphragm wall and prior to start of shaft excavation, facilitate installation of instrumentation as indicated in the Agreement Drawings.

D. Concrete Tremie: Place concrete through a metal hopper and into a rigid watertight tremie pipe, which is large enough to permit free flow of concrete and not less than 10 inches in diameter. Use tremie pipes of sufficient length and weight to discharge concrete within the base of the panel excavation. Equip the tremie tube so the bottom end closes if concrete does not encase the pipe. Do not use tremie pipes that contain aluminum parts that will have contact with the concrete.

2.3 SOURCE QUALITY CONTROL

A. At a minimum, include the following items in the Inspection and Test Plan:
1. Surveillance:
   a. Concrete batching plant inspection at a minimum of 7 days' notice.
   b. Steel / GFRP reinforcement fabrication yard inspection at a minimum of 7 days' notice.
2. Review:
   a. Not used.
3. Verification:
   a. Reinforcement product data.
   b. Concrete design mix.
   c. Support fluid design mix.
4. Witness Point:
   a. Not used.
5. Hold Point:
   a. Acceptance by Designer and Company if support fluid other than bentonite is proposed.

PART 3 - EXECUTION

3.1 GENERAL

A. Before excavating above or adjacent to existing utilities, notify the utility owner to ensure that any necessary protective work will be coordinated and performed by the Diaphragm Wall Contractor in accordance with the requirements of the utility owner involved. If existing service lines, utilities, and utility structures to remain in service are uncovered or encountered during these operations coordinate with Company regarding disposition of utilities.

B. Should uncharted or incorrectly charted piping or other utilities be encountered, immediately notify the Contractor and the utility owner. Cooperate with the utility owner in keeping their respective service, utility and facilities in operation. Repair damaged utilities to the satisfaction of the Company and the utility owner.

C. Protect existing Line 5 pipeline as required.

D. Clear site, excavate and roughen grade, install working platform as required to perform the work of this Section. Locally excavate for removal of obstructions and backfill as required.

E. Conduct work of this Section so as not to damage facilities or improvements that are to remain in place.

F. Stockpile materials and install support fluid plant only in staging areas within the property limits or designated work areas. Keep public ways and areas clear of all spillages from construction operations and from trucks hauling materials to or from the project site. Employ construction methods, including protective coverings when necessary, to prevent excavated material and/or support fluid from entering utilities and sewers, and to prevent all spillage onto streets, sidewalks or other facilities.

G. Protect all exterior surfaces of adjacent structures from damage and disturbance. Install screens and other protective measures, as necessary, to prevent support fluid dripping from excavating buckets, hydromill or chisels from blowing into streets, sidewalks and on to structures. At the completion of the concrete diaphragm wall construction, restore all exterior surfaces of adjacent structures to their original condition, as acceptable to the Company.

H. Employ construction methods and procedures that prevent spillage of excavated materials, support fluid or concrete onto utilities, streets, sidewalks or other facilities.

I. Prior to the start of construction, ensure all environmental protection measures are in place and functioning to ensure compliance with all regulatory and specification requirements, especially measures related to the capture and containment of excess support fluid as well as measures relating to the disposal of support fluid, noise barriers, silt fencing, berms, barriers and traps.

J. Do not begin panel or shaft excavation until the following conditions have been met:
   1. Pre-construction surveys have been completed.
   2. Installation of geotechnical instrumentation (other than that to be installed within the diaphragm wall) has been completed and baseline readings taken.
   3. All action submittals specified herein have been issued, reviewed and accepted.

3.2 PRE-EXCAVATION AND GUIDE WALL CONSTRUCTION

A. Before commencing diaphragm wall trench excavation, hand or vacuum excavate as and where required along the diaphragm wall alignment to expose all utilities known to cross or suspected of crossing the alignment and to determine the locations of potentially unknown utilities.

B. Guide Walls:
   1. Construct continuous, cast-in-place reinforced concrete guide walls in accordance with approved Shop Drawings, with due provisions for tolerances and clearances as well as for supporting shoring/bracing systems.
   2. Form construction joints as necessary along guide walls.
   3. Construct guide walls to an elevation that will allow a minimum elevation of diaphragm wall at ground surface.
   4. Construct on stable subgrade with suitable anchorages or other stabilizing measures, as necessary, to prevent movement during panel excavation, reinforcement installation and concrete placement.
   5. Construct at an elevation that will allow the lowest support fluid level in the trench (as defined in the Diaphragm Wall Contractor's trench stability calculations) to be maintained without leakage or contamination.
   6. Use suitable anchorage or other stabilizing measures as necessary to prevent guide wall movement.

C. If at any time the safety of any existing or new construction, utilities, roadways, walkways, or other facilities, appear to be endangered, take all necessary means to protect such structures, utilities, etc.

3.3 DIAPHRAGM WALL EXCAVATION

A. Layout and measure panels taking as reference the inner face of the wall as shown on the approved Shop Drawings.

B. Perform excavation by combinations of drilling, milling, clamming, chiseling, or other approved means. Use such means that will minimize over-excavation and loosening and caving of material outside designed trench width. Fill each panel and maintain with a stable suspension of support fluid throughout excavation. Perform excavation through the support fluid. Add support fluid to the excavated trench as necessary to maintain the support fluid level in accordance with Diaphragm Wall Contractor's approved work plans and trench stability analysis.

C. Anticipate that below ground obstructions may be encountered in excavating for panels and provide procedures and equipment for their removal. Remove obstructions by pre-trenching to the extent practicable and backfilling with suitable material. Select construction methods and equipment with consideration of the possibility that obstructions may be encountered within the diaphragm wall excavation. Contain excavated spoil. Recycle dirty support fluid to a central processing plant.

D. If obstructions larger than the width of the diaphragm wall excavation are encountered, cut, split, and remove from the excavation area.

E. Perform excavation of diaphragm wall panel trenches in the sequence and to the lines and grades as shown on the approved Shop Drawings. Excavate panels within the specified tolerances from

ground surface to the required minimum depths. Excavate in a manner that controls movement or loss of ground, movement of utilities or lowering of groundwater table. Remove all loose debris from the bottom of the panel excavation to ensure a trench bottom free of all loose soil, rock fragments, and debris. Take depth soundings to confirm that the trench bottom has been cleaned of all loose soil and rock fragments, and other foreign material.

F. Carefully control panel excavation in the vicinity of buildings, utilities, and other structures to suit site conditions and limit impacts on adjacent structures and utilities.

G. Dispose of all excavated materials and waste support fluid in accordance with applicable permits and regulatory requirements.

H. Take all necessary measures to prevent collapse of the excavated diaphragm wall trench prior to concrete placement. In the event collapse occurs, backfill with lean concrete and re-excavate per the approved Diaphragm Wall Contractor's work plans.

I. Do not excavate a new panel immediately adjacent to a previously completed panel until the concrete in that adjacent panel has been in place a minimum of 72 hours or has strength of at least 1800 psi. The minimum curing duration can be modified based on concrete cylinder strengths and with the approval of the Designer.

J. Do not excavate two adjacent panels at the same time. Sequence the work so that at least one of the following conditions is met:
   1. At least one concreted panel is left between two open panels.
   2. At least one panel of unexcavated ground remains between open panels at shafts with an inside diameter of at least 50 feet.
   3. Two panels of unexcavated ground remain between open panels at shafts with an inside diameter less than 50 feet.

K. Check the verticality of the panel during panel excavation continuously when using a hydromill and at no greater than 10-foot intervals when using a clamshell and make modifications to the excavation procedures as required to maintain verticality within the specified tolerances.

L. Maintain a reserve supply of mixed support fluid equal in volume to 50 percent of the volume of one fully excavated panel. If panel sizes vary, base the size of the support fluid reserve volume on the largest panel.

3.4 OBSTRUCTION REMOVAL FROM DIAPHRAGM WALL EXCAVATION

A. When obstructions are encountered, notify the Company promptly.

B. When efforts to advance past an obstruction to the base of the diaphragm wall result in a reduction in the rate of advance and/or change in approved means and methods relative to the approved diaphragm wall work plan, remove, bypass or break up the obstruction.

3.5 PLACING REINFORCEMENT

A. Before placing reinforcement in the support fluid filled trench, clean the joints of any adjacent panels to ensure the creation of a watertight bond between adjacent panels. If required, install and secure end stops prior to placing reinforcement in the support fluid filled trench.

B. Install PVC waterstops at all diaphragm wall panel joints.

C. Do not place the reinforcement cage until:
   1. The bottom of excavation has been inspected and the result accepted by the relevant entities identified in the ITP.
   2. Ultrasonic surveys or equivalent have been completed to confirm vertical alignment of the trench excavation meets the specified tolerances and to identify any significant irregularities in the excavated trench walls in comparison with the theoretical panel limits.
   3. The panel joint has been demonstrated to be clean in accordance with method described in Diaphragm Wall Contractor's approved work plan. An acceptable method would be observation of the passage down and up over the full height of the joint of a weighted cleaning tool suspended from the service crane. Uninterrupted passage without changes in alignment or slack in the crane cable would be required.
   4. The reinforcement cage has been inspected and found to conform with the approved Shop Drawings and requirements herein.
   5. The properties of the support fluid in the trench are determined to be within the ranges specified in the approved ITP.
   6. The final support fluid test has been performed in the presence of the relevant entities identified in the ITP and found acceptable.

D. If used, adequately restrain end stops at the top of the trench to prevent movement in any direction during concrete placement. Use filler material that prevents the migration of tremie concrete around the end stop, and which can be easily and completely removed during excavation of the adjacent panel.

E. Secure the reinforcing bars together in a manner that will provide a reinforcement cage of sufficient rigidity to resist distortion during lifting and placement into the trench. Do not place reinforcing cage assemblies that are distorted. Welding of the steel reinforcement will not be permitted.

F. Mark the reinforcement cage to indicate correct orientation and vertical alignment for proper insertion into the trench.

G. Fit the reinforcement cage with approved centering devices on both the exterior and interior faces. Locate centering devices at a maximum of 5 feet on-center horizontally, minimum two per level, and a maximum of 20 feet on center vertically.

H. Securely fasten all embedded items and forming items for keyways to the reinforcement to prevent their displacement during hoisting, setting of the steel and concrete placement. Form recesses and block-outs as detailed on the approved Shop Drawings using high-density Styrofoam, plywood and necessary steel fasteners, or other approved methods and securely fasten them to prevent displacement of the recess/block-out forming materials. Securely fasten embedded reinforcing bar couplers within the reinforcement cage to prevent them from moving and plug them to prevent them from filling with concrete during concrete placement.

I. Install outer casings for geotechnical instrumentation and grout pipes in diaphragm wall as required and secure them to the reinforcement cage, as necessary, to prevent them from moving during concrete placement. Replace any damaged or unusable instrumentation.

3.6 CONCRETE PLACEMENT

A. Commence concrete placement within 24 hours of completing excavation for each panel. Diaphragm Wall Contractor may propose a longer period subject to submittal and review of Diaphragm Wall Contractor's engineer's panel stability assessment.

B. Commence placement of concrete in the panels as soon as possible after completion of support fluid cleaning and panel bottom cleaning, and no more than two hours after reinforcement cage placement. Proceed continuously until completion of panel. If the time limitations specified above are exceeded, remove the panel reinforcing steel from the excavation and re-clean the support fluid and the bottom of excavation. Clean the steel of all support fluid and debris and repair any damage before reinstalling the reinforcing steel into the trench.

C. Do not place any concrete in the trench until the properties of the support fluid in the trench are determined to be within the ranges specified in the approved ITP.

D. Place concrete in the support fluid filled trench by the tremie method in such a manner that the concrete rises uniformly to displace support fluid from the bottom up and mixing of the concrete and support fluid does not occur. The inside and outside surfaces of the tremie pipe are required to be clean and smooth to permit both flow of concrete and unimpeded withdrawal during concrete placement operations.
   1. Ensure that initially there is a suitable separator at the bottom of the tremie pipe, which will not permit discharge until the concrete head has at least reached the top level of the support fluid. Thereafter, maintain a positive concrete head throughout.
   2. The bottom of the tremie shall be a maximum of 1 foot above the bottom of the excavation at the start of concreting.
   3. The tremie discharge end shall be immersed at least 10 feet in concrete at all times after the concrete reaches 11 feet above the diaphragm wall toe. The flow of concrete shall be continuous, suspended only as necessary to accommodate the staging of concrete trucks. Mark the tremie pipe in 5 foot intervals starting at the discharge end to allow ready determination of the tremie pipe depth.
   4. Determine the number and spacing of tremie pipes used for each panel from the requirement that the concrete level shall be kept approximately horizontal during the placement operations. Place tremie pipes approximately equidistant from the panel joints and each other. The horizontal flow of concrete required from a tremie pipe shall not exceed 8 feet.
   5. Measure concrete rise at not more than 10-foot vertical intervals at each joint and middle of the panel to confirm the concrete rise is level.
   6. Proceed continuously with panel concreting until concrete of the required consistency and quality reaches the top of diaphragm wall elevation.
   7. Do not move the tremie pipe horizontally.
   8. Cold joints within a diaphragm wall panel are not permitted. Any diaphragm wall panel that has a cold joint may be considered defective. Design and implement repair to the approval of the Designer.
   9. If at any time during the concrete placement, the bottom end of the tremie pipe is removed from within the fluid concrete and discharges concrete above the rising concrete level, the

panel will be considered defective. Design and implement repair to the approval of the Designer.

E. Top-of-wall Preparation: Remove by chipping concrete above top-of-wall elevation shown in Agreement Drawings. Resultant concrete surface shall be aggregate exposed and minimum ¼ inch amplitude. Alternative preparation approaches and acceptance requirements can be proposed for review and approval by Designer.

3.7 DIAPHRAGM WALL CLEANING

A. Clean with either high pressure water or rotary brushes after excavation.

3.8 DEFECTIVE DIAPHRAGM WALL PANELS

A. Diaphragm wall panels exhibiting the following deficiencies will be considered defective:
   1. Cold joints within a single panel.
   2. Areas of voids, honeycombs, laitance accumulation, aggregate runs, or pockets of segregated aggregate.
   3. Panels not meeting the tolerances specified herein, including deviations from plan position and plumbness, joint cleanliness, bulges and protrusions that extend beyond the design line.
   4. Water ingress through the diaphragm wall that violates the criteria specified herein.
   5. Areas of concrete contaminated with bentonite support fluid, bentonite pockets/inclusions, or dried bentonite.
   6. Concrete strength below specified minimum strength.
   7. Embedded items or block-outs not meeting location tolerances.
   8. Any other specification violations.

B. Inspect the watertightness of the diaphragm walls, at a minimum, on a monthly basis, starting after exposure of the wall panels during excavation, and continuing until final acceptance.

3.9 CORRECTIVE ACTION

A. If a defective diaphragm wall panel is identified during diaphragm wall installation, do not commence construction of another diaphragm wall panel until given approval to proceed by Designer.

B. Submit corrective action for all defective diaphragm wall panels for approval. Non-conforming panels are panels not meeting the design requirements indicated on the Agreement Drawings or specified herein.

C. Perform corrective actions in accordance with approved Corrective Action Plan designed to be effective for the design life of the defective element. Corrective Action Plans can be submitted for pre-approval as required.

3.10 GEOTECHNICAL INSTRUMENTATION AND MONITORING

A. Provide unrestricted and safe access to geotechnical instrumentation locations, allowing measurements to be taken, as necessary.

3.11 FIELD QUALITY CONTROL

A. At a minimum, include the following items in the Inspection and Test Plan:
   1. Surveillance:
      a. Proper tremie concrete initiation procedures.
   2. Review:
      a. Diaphragm wall installation records.
   3. Verification:
      a. Concrete test results.
      b. Tremie pipe control within specification requirements.
      c. Panel verticality measurements.
   4. Witness Point:
      a. Support fluid condition and test results during excavation.
   5. Hold Point:
      a. Guide walls installed, surveyed and confirmed to meet specification requirements.
      b. Diaphragm wall panel excavated in accordance with specification requirements, including within plan position and verticality tolerances.
      c. Diaphragm wall base inspection and acceptance.
      d. Diaphragm wall panel joint cleanliness and acceptance.
      e. Support fluid condition and test results prior to reinforcement placement.
      f. Reinforcement cage compliance with specification and approved Shop Drawings.
      g. Reinforcement / steel soldier pile placed into diaphragm wall panel in accordance with specification requirements.
      h. Support fluid condition and test results prior to concreting.
      i. Exposure, inspection and acceptance of top 10 feet of outside face of two of first ten panels at each location.
      j. Proper top-of-wall preparation.

B. Special Inspection: Provide access for the Special Inspector to perform independent QC activities as follows:
      a. Continuous inspection of panel excavation operations and maintenance of complete and accurate records for each panel.
      b. Continuous inspection and record keeping for each panel to verify placement locations and plumbness, confirm element sizes and lengths, and record concrete volumes.
      c. Periodic inspection of reinforcement prior to placement, and verification of placement.
      d. Periodic inspection to verify weldability of reinforcing bars other than ASTM A706.
      e. Periodic inspection of single pass filet welds of maximum size 5/16 inch.
      f. Continuous inspection of all other welds.
      g. Periodic inspection of anchors cast in concrete.
      h. Periodic inspection of mechanical anchors.
      i. Periodic inspection to verify use of required design mix.
      j. Continuous inspection to fabricate specimens for strength tests, perform slump and air content tests, and determine the temperature of the concrete.

k. Continuous inspection of concrete and shotcrete for proper application techniques.
l. Periodic inspection to verify maintenance of specified curing temperature and techniques.
m. Periodic inspection to verify in-situ concrete strength prior to removal of shores and forms from beams and structural slabs.
n. Periodic inspection of formwork for shape, location and dimensions of the concrete member being formed.
o. Periodic inspection of welded or bolted end connections.

C. Responsibilities for QC testing and inspection:
1. Furnish notification, with at least one business days' notice, for all diaphragm wall fabrication and installation operations.
2. Furnish material samples as required for testing.
3. Furnish access and proper facilities, including but not limited to scaffolding, temporary work platforms, and hoisting facilities, as required for inspection and testing.
4. Furnish labor as required to facilitate testing and inspection of all diaphragm wall work.
5. Provide temperature and humidity-controlled storage facilities for concrete cylinders and grout cubes, as appropriate.
6. Provide all additional diaphragm wall inspection and testing required by Contractor, Company or Designer as a consequence of diaphragm wall work not demonstrating compliance with this specification, performed without prior notice, or performed contrary to previously approved submittals.
7. Perform ultrasonic "Koden" surveys or equivalent to confirm that the trench has been excavated to the required dimensions and to the required tolerances. Carry-out soundings at sufficient locations to provide adequate accuracy and resolution over full height of panel and around entire perimeter.
8. Raise and lower joint cleaning device or hydromill along panel joints and perform all necessary operations to confirm joints have been cleaned and cleared of all materials.

D. Inspections:
1. As-Excavated Panel Geometry: After each panel is excavated to required depth, verify the exact three-dimensional geometry and location of the panel. Verify using an Ultrasonic Drilling Monitor, model DM-684, manufactured by Koden Electronics Company, or approved equivalent. Correct panels exceeding the permissible tolerances by backfilling with lean concrete and re-excavating them within the required tolerances before placement of reinforcement and final concreting proceeds. Alternatively, the panel may be over-excavated to correct diaphragm wall panel alignment provided the minimum shaft internal radius shown on the Agreement Drawings is maintained.
2. Trench Bottom Inspection: Carry out inspection using a tape weighted with a 4 inch × 4 inch square of 1 inch thick steel plate weighing approximately 2 lbs which hangs horizontally from the tape. Have replacement weighted tapes available at all times during construction. Supplementary measures to assess the condition of the base of the excavation can be proposed for review by the Designer, and could include use of a steel rod suspended from a crane that is raised and lowered in a controlled manner under the observation of an inspector. Measure and record the trench bottom elevation at a minimum of 6 locations of in the presence of the Designer, or their designated representative, at the following stages to determine whether soil from trench sides or other sediment has collected:
a. Immediately after excavation to the final depth.
b. Immediately after each cleaning and de-sanding.
c. Immediately before and immediately after placement of steel.
d. Immediately before placement of concrete.

3. Excavation Inspection:
   a. Perform excavation inspection as excavation progresses. Immediately inform the Company and Designer of over-excavation, obstructions, boulders, or excavation that is out of tolerance.
   b. Use inspection devices as identified herein before tremie concreting, to demonstrate that the trench has been excavated to the specified width, depth and verticality, the cleanliness of trench bottom; and to ensure that joint continuity is maintained and that concrete from previous placements has not encroached upon the panel or into the joint.
4. Early Panel Outside Face Inspection:
   a. Excavate to expose the top ten feet of at least two of the first ten panels constructed at each location within one week of receiving test results demonstrating adequate concrete strength gain of the target panel.
   b. Observe and record the condition of the outside face of the panel, including filter cake nature and thickness and cover-zone concrete quality. Once recorded, remove the filter cake to allow the concrete to be observed.

E. Testing:
1. Concrete Testing: Conduct testing and inspection of concrete used in diaphragm walls to demonstrate that concrete conforms to the requirements stated herein. Employ testing laboratory to provide specified inspection and testing.
2. Bentonite Support Fluid Testing: Performed by the Diaphragm Wall Contractor as required hereinafter with the results of every test submitted within the time limit specified herein. Testing methods and equipment shall be in accordance with API RP 13B-1.
   a. Required Tests:
      1) Density, by mud density balance.
      2) Viscosity, by Marsh Cone Method.
      3) pH.
      4) Fluid loss, by filter press.
      5) Sand content.
      6) Filter cake thickness in accordance with API 13A and 13B.
   b. Testing Frequency for Each Panel:
      1) Density, viscosity and pH:
         a) Daily on fresh support fluid.
         b) During panel excavation (at least twice per shift).
         c) At completion of panel excavation.
         d) Immediately prior to installation of steel.
         e) Immediately before placing concrete.
         f) Prior to re-use.
         g) After every rainfall.
      2) Sand Content:
         a) During panel excavation (at least once per shift).
         b) At completion of panel excavation.
         c) Immediately prior to installation of steel.
         d) Immediately before placing concrete.
         e) Prior to re-use.
      3) Fluid Loss and Filter Cake Thickness:
         a) At least once every 2 days.
   c. Calibration: Calibrate density measuring and viscosity measuring devices monthly, or as otherwise stated in the Inspection and Test Plan (ITP), in accordance with applicable API and ASTM standards and to ensure correct calibration to an accuracy

of plus or minus 0.05 pcf for density and 0.07 percent of the reading taken for viscosity.

d. Perform API fluid loss test, by filter press, in accordance with API RP 13B-1.

e. Sampling: Take and test samples from the top (upper two feet of support fluid filled trench) and bottom (5 feet above the bottom of support fluid filled trench) of each panel (and middle of each panel just prior to placement of reinforcement cage). Do not mix samples.

3. Support Fluid Testing for Non-Bentonite Support Fluid:
   a. Perform in accordance with manufacturers guidance and approved Inspection and Test Plan (ITP).
4. Packer Permeability Testing:
   a. Complete in accordance with dewatering design if required.
   b. Fill any exploration holes outside the Diaphragm Wall with cement grout after all testing and/or grouting is completed.

F. Survey Control:
1. For guidewalls used as reference points, as reference lines, or as benchmarks for routine control of diaphragm wall construction, verify elevation and location of guidewall on a daily basis during panel excavation.
2. Use benchmarks, which are not affected by diaphragm wall construction, and control diaphragm wall construction by survey methods.

G. Monitoring:
1. Comply with the requirements of Section 310913 “Geotechnical Instrumentation and Monitoring”.

H. Installation Tolerances: Construct within tolerances stated below or as stated on the Agreement Drawings, whichever are more stringent:
1. Guidewalls: The finished face of the guidewall facing the panel trench and on the side of trench nearest the shaft excavation shall be vertical and shall represent the theoretical inside face of the diaphragm wall. There shall be no ridges or abrupt changes on the face and its variation from straight line shall not exceed ½ inch in 10 feet. Design, construct and maintain guidewalls to enable construction of the diaphragm wall panels to the tolerances indicated herein.
2. Diaphragm Wall Layout at Grade:
   a. Center of Shaft: Within plus or minus 1 inch.
   b. Top Elevation of Shaft: Within plus or minus 2 inches.
   c. Location of Panel at Grade: Within plus or minus 1 inch of theoretical location.
3. Diaphragm Wall:
   a. Verticality: 0.5%
   b. Minimum Wall Thickness: As specified on Agreement Drawings.
   c. Minimum Panel-to-Panel Overlap: As specified on Agreement Drawings.
   d. Remove any localized protrusions or bulges which extend beyond the design line. The finished inside wall surface including diaphragm wall deformations from excavation shall not encroach on the minimum clearances shown on the Agreement Drawings.
   e. In the event of any diaphragm wall cavities that compromise the wall design, the panel will be considered defective. Design and implement repair to the approval of the Designer.
4. Formed Recesses and Embedded Items:

a. Anchorage plates, formed recesses for slab and beam keyways, pipe sleeves, dowels, studs and other embedded items shall be within plus or minus 2 inches horizontally and vertically.

5. Reinforcement Cage Placement:
   a. Normal to Wall: Excavation tolerance plus or minus 1 inch for reinforcement cage.
   b. Parallel to the Wall/Panel in Horizontal Direction: Plus or minus 2 inches.
   c. Vertical: Plus or minus 2 inches.
   d. Minimum Concrete Cover on Reinforcement Bars: 3 inches, unless otherwise noted on the Agreement Drawings.
6. The accuracy of the Koden (ultra sonic drilling monitor) or approved equivalent shall be in accordance with the industry standards and the manufacturer's data sheets with a recording unit accuracy of ±0.2%.

I. Watertightness:
1. Evaluate and appraise panel wall leakage vulnerability by monitoring diaphragm wall performance as excavation proceeds.
2. Assess watertightness under the design external groundwater elevation or as agreed with the Designer and Company.
3. In cases where the wall is not protected from weather conditions, assessment of watertightnesss shall take place only when the following weather conditions apply:
   a. Air temperature is above 32 deg F and below 80 deg F.
   b. No direct sunlight falls on any wall surface being assessed.
   c. No precipitation has occurred in the 24 hours preceding the assessment.
4. Record the groundwater level, air temperature and weather conditions for each assessment.
5. Repair any areas in which the following watertightness criteria are not achieved:
   a. No flowing water is visible between the top of the wall and the top of the temporary base slab (seeping of water is permitted).
   b. Damp patches on the front face of the wall are permitted provided that all the following criteria are met:
      1) The total area of dampness does not exceed 10% of the visible area of the front face.
      2) No individual patch of dampness has an area in excess of 50 square feet.
   c. Total leakage shall not exceed 0.2 gpm per 10,000 square feet of exposed diaphragm wall between the top of the wall and the top of the temporary base slab.

J. Should the Designer determine that a defective panel requires post-repair, propose design repairs and submit associated structural design calculations signed and sealed by a Registered Professional Civil Engineer licensed in the State of Michigan to demonstrate that the repaired panel is structurally acceptable.

END OF SECTION 315600

SECTION 317117 – BACKFILL GROUTING

PART 1 - GENERAL

1.1 SUMMARY

A. Section includes requirements for performing backfill grouting and check grouting during tunneling to ensure continuous contact of the precast concrete lining installed by the Tunnel Boring Machine (TBM) with the surrounding ground.

B. Related Requirements:
   1. Section 310179 “Sealing Leaks” for sealing the precast tunnel lining if water leakage exceeds the specified leakage criteria.
   2. Section 317119 “Excavation by Tunnel Boring Machine” for completion of the bored tunnel with the use of a Pressurized Face Tunnel Boring Machine (TBM), including installing the permanent tunnel lining consisting of gasketed precast concrete segments.
   3. Section 317416 “Precast Concrete Tunnel Lining” for manufacturing, handling, transporting and installing gasketed precast concrete tunnel lining (PCTL) segments.

1.2 DEFINITIONS

A. Annular Gap: The void space between the outside of the segmental tunnel liner and the excavated ground including TBM overcut and unexpected voids due to lost ground during tunnel excavation.

B. Backfill Grouting: Grouting between tunnel liner and excavated surface from ports within the tail of the TBM.

C. Check Grouting: Grouting through the segmental lining, normally above tunnel crown, under pressure to ensure all exterior voids are being completely filled. Check grouting may also be performed using permeation or chemical grouts to limit groundwater inflows.

D. Gel Time: The time after the A and B components of a two-component grout are mixed at which the grout ceases to be fluid.

E. Refusal: When the total amount of grout injected during check grouting is less than four gallons as measured over a continuous two-minute period at the maximum specified pressure.

F. Shunt Flow: The migration of groundwater and contaminants within or around the annular gap and previously placed backfill grout.

G. Two-component Grout: Two-component grouts consist of an A and B component. The A-Component is a stabilized grout containing varied combinations of water, binders, bentonite and admixtures. The B-Component is a liquid accelerator that is added to the A-Component as it is being injected into the annulus.

H. Verification Test: Use of non-destructive testing or similar method to confirm that the annular gap is full of grout or identify zones where backfill grouting is incomplete.

1.3 REFERENCES

A. ASTM International (ASTM):
1. ASTM C94/C94M Standard Specification for Ready-Mixed Concrete.
2. ASTM C109 Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens).
3. ASTM C150/C150M Standard Specification for Portland Cement.
4. ASTM C403/C403M Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance.
5. ASTM C494/C494M Standard Specification for Chemical Admixtures for Concrete.
6. ASTM C618 Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.
7. ASTM D2166 Standard Test Method for Unconfined Compressive Strength of Cohesive Soil.

1.4 PREINSTALLATION MEETINGS

A. Not used.

1.5 ACTION SUBMITTALS

A. Product Data: Material data sheets and material certificates of compliance and documentation showing that the proposed materials have a history of demonstrable satisfactory performance and are compatible with adjacent materials.
1. Standard physical and chemical analysis data of cement.
2. Fly ash.
3. Bentonite.
4. Stabilizing agent.
5. Accelerator.
6. Fluidifier.
7. Sources of supply for each grout ingredient.
8. Other chemical admixtures for the cement grout mixes.

B. Proposed Testing Methods: Provide details of the proposed testing approach for both preconstruction and production testing for flowability, viscosity, bleed, segregation, stabilization time, gel time and compressive strengths, including standards to be used (ASTM or similar).

C. Submit as part of the tunnel work plan in Section 317119 “Excavation by Tunnel Boring Machine”, a description of the backfill and check grout systems including mixes, methods, and procedures proposed, demonstrating that they provide the required strength, limiting deformation and strength gain characteristics. Include:
1. A description of the grouting systems to demonstrate the capability of complete, immediate, and uniform filling of the annular gap as the TBM advances, and how grout gel time and strength gain is designed to ensure consistency with the planned rates of advance of the TBM. Describe method of measuring grout filling volumes and pressures and logic

used to determine grout composition and pressures as a function of tunnel depth, grouting pressure, rate of advance, ground, and groundwater conditions including shunt flow.

2. Grout mix design report for each of the grouting techniques, with tests performed at the minimum, average and maximum grouting pressures, including:
    a. Grout type and designation.
    b. Grout mix constituents and proportions, including materials by weight and volume.
    c. Grout densities and viscosities, including wet density at point of placement.
    d. Grout gel times.
    e. Bleeding, shrinkage/expansion.
    f. Compressive strength.
    g. Additives such as retarders and accelerators and sources and properties of all components.
    h. Results of laboratory tests on the mix designs including compressive strengths in accordance with ASTM C109, gel times, and the change of the cement grout characteristics based on the properties and proportions of approved admixtures.
    i. How grout will perform under shunt flows due to working with reduced face support pressures, and defining any limits for shunt flow rates.
3. Location of mixing equipment, pumps, injection points including location of mixing plant, grout delivery system, grout pumping system.
4. Grout delivery system design and technical specifications.
5. Grout pumping system design and technical specifications.
6. Pressure measurement and maximum allowable pressure.
7. Certification of calibration of pressure gauges and volumetric flow meters.
8. Grout volume measurement.
9. Measurement procedures for grouted volume or grout takes.
10. Testing procedures.
11. Description of proposed grouting sequence, calculated injection pressures including variation along alignment, grout materials, mix proportions, and procedure for altering mix proportions based on observed grout take.
12. Methods to achieve uninterrupted grouting.
13. Methods to avoid grout segregation.
14. Methods to demonstrating the injected grout completely filled the annular gap.
15. Means and methods for collecting and disposing of excess material and collecting and disposing of water resulting from grouting operations.
16. Methods for assuring that injection pressures do not damage the segmental lining or adjacent work.
17. Methods for preventing grout migration into the TBM cutterhead from behind the tunnel shield.
18. Methods for cleaning the grouting system and injection points through the tailskin.

D. Details of the preconstruction testing program including strength gain of accelerated backfill grout at an age of 1, 4, 8 and 24 hours and 28 days.

E. Report on verification test demonstrating satisfactory performance. Include basis of method, method procedure, evidence of successful use on prior projects or prototype evidence of success otherwise and results of verification test.

F. Check hole drilling and sealing procedures and equipment.

1.6 INFORMATIONAL SUBMITTALS

A. Qualification Data:
   1. Grouting manager.
   2. Testing laboratory.
   3. Field sampling and testing personnel.

B. Certifications:
   1. Weekly calibration certificates for pressure gauges and volumetric flow meters.
   2. Certification that all admixtures are noncorrosive.
   3. Monthly certificates from an approved testing laboratory verifying accuracy of master grouting pressure gauges.

C. Add the following information to the segment tracking database within 24 hours of grouting or testing:
   1. For each segment:
      a. All backfill grout mix data including batch number, mix proportions, viscosity, setting times, related test results and any modifications made to the mix during grouting operations for the ring of which the segment is a part.
      b. Volume, pumping rate, and grout pressure for backfill grouting pumped for the ring of which the segment is a part.
   2. For each segment on which the verification test is performed:
      a. Images from test.
      b. Interpretation of test data.
   3. For each segment where check grouting is performed:
      a. Date of check grouting, with start and finish times.
      b. Grout mix data including mix proportions and related test results.
      c. Volume, pumping rate, and grout pressure for check grout pumped through grout port.
      d. Descriptions of interruptions or other difficulties experienced in grouting operations, including grout escapes and observations during drilling.
      e. Change in groundwater inflows, if any, from the rings at or near check grouting locations.

1.7 QUALITY ASSURANCE

A. Qualifications:
   1. Grouting Manager: Minimum of 5 years of related work experience on similar projects to manage the grouting program by designing, testing, and overseeing the injection of grout mixes of the type required.
   2. Testing Laboratory: Laboratory testing shall be performed by an independent testing company/firm with an established record of at least three years of experience in performing the standardized tests that are required for the grouting operations.
   3. Field sampling and testing personnel shall be ACI Concrete Field Testing Technicians - Grade I certified by an ACI-certified testing laboratory.

1.8 PRECONSTRUCTION TESTING

A. Backfill Grout Trial Mix:
   1. Test unconfined compressive strength at 1hour, 4 hours and 24 hours, 7 days, and 28 days with three (3) samples for each. The compressive strength shall be the average of the three (3) samples tested for each trial mix. Samples with a strength of more than 200psi should be tested in accordance with ASTM C109.
      a. If penetrometer or Vicat testing is proposed for early age compressive strength testing during production testing, then provide a comparison between early age strength tests results from the proposed method and grout cubes, tested using a strain based method based on ASTM D2166 for strengths of less than 200psi.
   2. In addition, test for flowability, viscosity, bleed, segregation and stabilization time.
   3. Test gel times per ASTM C403 to satisfy specified criteria.
   4. Washout Test: Perform tests on trial mix to determine grout resistance to washout. Prepare mockup representing field conditions, including pressure, and apply the grout trial mix under expected rate of flowing water from shunt flows based on pressure differential due to working with reduced face support.

B. Check Grout Trial Mix:
   1. Test unconfined compressive strength at 7 days, and 28 days per ASTM C109 with three (3) samples for each.
   2. In addition test for bleed and segregation.

C. Verification Test:
   1. Set up a verification test trial using an actual segment and the proposed backfill grout mix to demonstrate that the verification test can detect water or air filled voids in the grout of 4 inches in depth, 6 inches in width and 36 inches in length at various orientations to the segment.
   2. Perform verification tests 12 hours and 3, 7, 14 and 28 days after placing the grout.

1.9 DELIVERY, STORAGE, AND HANDLING

A. Deliver, store, and handle all materials as prescribed by the manufacturers of these materials in original, unopened containers with the manufacturer's name, product labels, product identification, and as detailed on the accepted data sheets. Protect materials from mechanical and environmental damage. Maintain sufficient amounts of required materials to assure continuous grouting operations.

B. Furnish cement/grout mix either in sacks or in bulk. Use material in chronological order of delivery. If furnished in bulk, provide accurate weighing devices to properly measure cement weight.

C. Package and store fly ash in accordance with their respective ASTM standards.

1.10 FIELD CONDITIONS

A. Not used.

PART 2 - PRODUCTS

2.1 GROUT MATERIALS

A. Do not use materials including admixtures that are toxic or cause any hazard to workers or the environment.

B. Water: Potable or recycled water meeting the requirements of ASTM C94.

C. Portland Cement: Type II or Type III meeting the requirements of ASTM C150.

D. Admixtures: Conform to ASTM C494, shall be compatible with other grout materials, and shall not promote steel corrosion.

E. Fly Ash: Conform to ASTM C618, Class F.

F. Sodium Silicate: Liquid solutions of soda (Na2O) and silica (SiO2) in water, manufactured from sodium silicate glass: a melted solution of high purity sand with soda ash. Sodium silicates shall have a pH range of 11-12. The range of silica:soda ratios and total dissolved solids shall have a demonstrated performance on a minimum of three tunnel projects in the last 5 years. Sodium silicate shall be supplied by PQ Corporation or Company-approved equal.

2.2 EQUIPMENT

A. Provide for the Backfill Grouting and Check Grouting:
   1. For equipment to be used for backfill grouting between precast concrete tunnel lining and excavated surface in TBM driven tunnels, see Section 317119, "Excavation by Tunnel Boring Machine".
   2. Equipment for Mixing and Injecting Grout: Designed for grouting service; maintained for duration of work to be capable of mixing, agitating, and transporting grout in a continuous flow at required pressure using a high speed colloidal mixer.
   3. Provide grout pump capable of developing in a continuous, uniform manner the desired pressure to the grouting location up to the maximum pressure required.
   4. Hose for Check Grouting: inside diameter not less than 1-1/2 inches, and capable of withstanding maximum water and grout pressures used.
   5. Arrange grouting equipment to provide for continuous circulation of grout in the system and to permit accurate pressure control at grout socket connection. Keep equipment and lines clean by constant circulation of grout and by periodic flushing with water.
   6. Configure equipment so flushing can be accomplished with grout intake valves closed, with water supply valve open, and with grout pump running at full speed.
   7. For check grouting, provide two pressure gauges, one at grout pump and other on manifold hookup at collar of grout socket being grouted. Use pressure gauges with ranges that include maximum required injection pressure, and that can be read to an accuracy of psig or better.
   8. Furnish accurately calibrated, high-precision master pressure gauge; use for periodic checking of accuracy of gauges used in grouting.
   9. Provide suitable stop valves at collar of grout socket for use in maintaining pressure, as required, until grout has set.

10. Provide a totalizing type volumetric flow meter that reads in liters or cubic feet, to an accuracy of +/-1%, to accurately determine amount of grout injected.
11. For check grouting equip pump or injection assembly with bypass valve to prevent sudden excessive grout pressure from developing at the grout socket connection.

B. Equipment for Check Grouting:
1. Use rotary or percussion drilling equipment with sufficient power and versatility to drill grout holes at any angle with the diameters and to the depth in accordance with the requirements herein. Utilize suitable valves or preventers to avoid significant inflow of groundwater while drilling through the segment.
2. Provide suitable valves and accurate, calibrated in-line pressure gauges and volumetric flow meters at the point of injection, so that the pressure and grout flow at the grout socket may be continuously monitored and regulated. Provide additional pressure gauge(s) at the grout pump. Check accuracy of gauges periodically, with an accurately calibrated high precision pressure gauge, maintained in working order and available at all times during grouting operations.
3. Use equipment that will not permit the specified pressure to be exceeded for each grout type. Provide suitable stop valves at the collar of each hole for use in maintaining pressure as required until grout has set.
4. Packers: Capable of sealing grout holes without leakage when grouting at the maximum specified pressure.

2.3 GROUT MIXES

A. General Design Criteria:
1. Design grout mixes with the appropriate properties to fully serve their intended functions, as defined herein. Include limits and proposed test standards (ASTM) for flowability, viscosity, bleed, segregation, stabilization time, gel time and other mix design details in the grout mix design report.
2. Backfill grout shall be a two-component grout. Gel time of the backfill grout mixes shall be controllable, by accelerator, to a minimum of 0.5 minutes in all anticipated field conditions including the full range of anticipated pressures to prevent washout.
3. Compressive strength for backfill grout:
    a. Minimum 20 psi in 1 hour.
    b. Minimum 150 psi in 24 hours.
    c. Minimum 500 psi in 28 calendar days.
4. Compressive strength for check grout:
    a. Minimum 500 psi in 28 calendar days.

B. Grout mixes to meet the following requirements for the grout mixes for each of the specified grouting types:
1. Propose a suitable grout mix for each set of ground conditions to be encountered along the tunnel drives.
2. Grouts sufficiently fluid as to ensure that they flow freely under pressure into all of the space to be filled.
3. Grouts capable of resisting washout by anticipated groundwater flows and of supporting construction loads.
4. Set-up times for segment backfill grout through TBM tail shield shall be compatible with rate of advance of the TBM and to avoid entrapment of the TBM.

2.4 SOURCE QUALITY CONTROL

A. At a minimum, include the following items in the Inspection and Test Plan:
   1. Surveillance:
      a. Not used.
   2. Review:
      a. Material certificates.
   3. Verification:
      a. Not used.
   4. Witness Point:
      a. Not used.
   5. Hold Point:
      a. Not used.

PART 3 - EXECUTION

3.1 GENERAL

A. Have all necessary equipment and materials, at sufficient quantity, and in good working order along with all required qualified personnel to perform the grouting operations in accordance with this Section.

3.2 TESTING OF GROUT MIXES

A. Perform preconstruction testing on grout mixes to demonstrate that each mix design meets the required properties specified.

B. Carry out site trials for each mix and delivery system prior to the commencement of tunneling to demonstrate that the proposed system works with the adopted equipment. The trials shall also demonstrate the properties of each grout mix, including gel time, and its suitability for the ground conditions.

3.3 BACKFILL GROUTING

A. Perform backfill grouting of the annular gap to ensure the precast concrete tunnel lining is in full and intimate contact around its entire perimeter and all surrounding voids are filled.

B. Perform backfill grouting of the annular gap continuously and simultaneously as the TBM progresses forward, with no lag between annulus gap volume being created by the TBM advance and being filled with backfill grout. Perform segment backfill grouting only though the tailskin of the TBM.

C. Incorporate accelerators at the point of injection of the grout.

D. Continue grouting until either the minimum volume as calculated based on the theoretical volume of the gap annulus and minimum pressure criteria been satisfied, or the maximum grout pressure as approved in Section 319119 “Excavation by Tunnel Boring Machine” is reached.

E. Do not exceed maximum approved grout pressures, and in no case exceed a pressure of 2 bar above hydrostatic pressure. Control grout pressures to prevent damage to the tunnel lining, surface blow-out, or surface deformations.

F. Grout Volume Monitoring:
   1. Monitor volume of grout placed for each ring.
   2. Determine theoretical volume of grout considering cut diameter and anticipated ground convergence.
   3. If the volume of backfill grouting for a ring is less than 90% or greater than 150% of the theoretical volume, perform verification test within 12 hours and adjust backfill grouting procedure as necessary if voids are found.

3.4 VERIFICATION TEST OF BACKFILL GROUTING

A. Use nondestructive testing (e.g. ultrasonic, ground penetrating radar, etc.), or similar method approved by the Designer, to confirm that the annular gap is full of grout or identify zones where backfill grouting is incomplete.

B. For the first 50ft of the tunnel drive in any reach of a new ground strata, perform verification on the full surface area of the precast concrete tunnel lining. Subsequently test the full surface area of every 100th ring placed. Perform the verification test at a time, or a series of times, when it can be performed before lining is obstructed by vent line, utilities or other obstructions.

C. Review backfill grouting records on a daily basis. When grout volume monitoring identifies a risk that the annular gap of a ring might not be completely filled, or shunt flows occur, perform an addition verification test on the full surface area of that ring.

3.5 CHECK GROUTING

A. If the verification of backfill grouting identifies voids in the backfill grouting greater than six inches in any direction, agree with Designer if check grouting should be performed to fill voids.

B. Use grout sockets in precast concrete segments for grouting:
   1. Extend the opening through to the exterior surface of the segment by drilling in a manner that does not cause damage to the concrete beyond the diameter of the socket.
   2. Drill grout holes until native ground is reached.
   3. Drill out a least one adjacent socket to allow venting and communication of grout.

C. Perform check grouting in a manner that ensures that voids are filled with grout and refusal is reached.

D. Upon completion, place a grout plug and leave each drilled-out grout socket in a condition in which the grout plug can be removed without damage to it or any part of the socket or the surrounding concrete, the grout socket can be drilled out, grouting can be carried out and the grout plug replaced such that all leaks are sealed.

E. Advance grouting operations in a constant direction along the tunnel.

F. Do not exceed maximum pressures specified. Control grout pressures to prevent damage to the tunnel lining, surface blow-out, and surface deformations.

3.6 CLEANUP

A. During grouting work, provide means for adequate collection and disposal of waste grout and wastewater produced by grouting operations.

B. Repair any leaking grout sockets in accordance with Section 317116 “Tunnel Leak Sealing”.

3.7 FIELD QUALITY CONTROL

A. At a minimum, include the following items in the Inspection and Test Plan:
   1. Surveillance:
      a. Backfill grout injection.
      b. Verification testing.
      c. Check grouting.
   2. Review:
      a. Grout volume and pressure monitoring.
      b. Grout test results.
      c. Pressure gage and volumetric flow meter testing.
   3. Verification:
      a. Comparison of actual and theoretical grout volumes.
      b. Verification test results.
      c. Check grout pressure and volume records.
   4. Witness Point:
      a. Site trials for each grout mix and delivery system.
      b. Verification test trial.
      c. Check grout sockets are drilled out until native ground reached.
      d. Pressure gage and volumetric flow meter testing.
   5. Hold Point:
      a. Not used.

B. Production Grouting: Test unconfined compressive strength at 1 hour (for two-component grout only), 24 hours, and 28 calendar days, in addition to flowability, viscosity, bleed, segregation, stabilization time and gel times. Perform one set of tests for every 350 cubic yards of each type of grout mixed.

C. Pressure Gages and Volumetric Flow Meters:
   1. Test field pressure gages and volumetric flow meters no less often than weekly using master gages and meters.
   2. Verify accuracy of master pressure gages and volumetric flow meters through the use of a test laboratory no less frequently than every month.

END OF SECTION 317117

SECTION 033000 - CAST-IN-PLACE CONCRETE

PART 1 - GENERAL

1.1 SUMMARY

A. Section includes cast-in-place concrete, including formwork, reinforcement, and finishes.
   1. Temporary support of excavation, including diaphragm walls and capping beams.
   2. Permanent earth retaining structures, including diaphragm walls and capping beams.
   3. Permanent slabs-on-grade within conditioned buildings.
   4. Temporary slabs-on-grade in unconditioned spaces and exteriors.
   5. Foundations for permanent buildings.
   6. Concrete on metal deck.
   7. Miscellaneous concrete: duct banks, gutters and curbs.

B. Related Requirements:
   1. Section 033100 “Structural Concrete Materials” for concrete materials, mixture design and placement procedures.
   2. Section 051200 “Structural Steel Framing”.
   3. Section 310179 “Sealing Leaks”.

1.2 DEFINITIONS

A. Cementitious Materials: Portland cement alone or in combination with one or more of the following: blended hydraulic cement, fly ash, slag cement, other pozzolans, and silica fume; materials subject to compliance with requirements. Refer to Section 033100 “Structural Concrete Materials”.

B. W/C Ratio: The ratio by weight of water to cementitious materials. Refer to Section 033100 “Structural Concrete Materials”.

C. Regroutable Hose: Hose which can be positioned in construction joint and which can be grouted, flushed and regrouted with polyurethane grout to seal leaks.

1.3 REFERENCES

A. American Association of State Highway Transportation Officials (AASHTO)
   1. AASHTO M 182 Standard Specification for Burlap Cloth Made from Jute or Kenaf and Cotton Mats.

B. American Concrete Institute (ACI)
   1. ACI 117 Specification for Tolerances for Concrete Construction and Materials and Commentary.
   2. ACI 207.1R Guide to Mass Concrete.
   3. ACI 301 Specifications for Structural Concrete.
   4. ACI 302.1R Guide to Concrete Floor and Slab Construction.

5. ACI 304R Guide for Measuring, Mixing, Transporting, and Placing Concrete.
6. ACI 305.1 Specification for Hot Weather Concreting.
7. ACI 305R Guide to Hot Weather Concreting.
8. ACI 306.1 Specification for Cold Weather Concreting.
9. ACI 306R Guide to Cold Weather Concreting.
10. ACI 308.1 Specification for Curing Concrete.
11. ACI 309R Guide for Consolidation of Concrete.
12. ACI 117 Specification for Tolerances for Concrete Construction and Materials.
13. ACI 318 Building Code Requirements for Structural Concrete.
14. ACI 347R Guide to Formwork for Concrete.
15. ACI 347.3R Guide to Formed Concrete Surfaces.
16. ACI 355.2 Qualification of Post-Installed Mechanical Anchors in Concrete.
17. ACI 355.4 Qualification of Post-Installed Adhesive Anchors in Concrete.
18. ACI 546R Guide to Concrete Repair.
19. ACI 546.3R Guide to Materials Selection for Concrete Repair.
20. ACI SP-004 Formwork for Concrete.
21. ACI SP-066 ACI Detailing Manual.

C. ASTM International (ASTM)
1. ASTM A184 Standard Specification for Welded Deformed Steel Bar Mats for Concrete Reinforcement.
2. ASTM A615 Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement.
3. ASTM A706 Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement.
4. ASTM A767 Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement.
5. ASTM A780 Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings.
6. ASTM A1064 Standard Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete.
7. ASTM C33 Standard Specification for Concrete Aggregates.
8. ASTM C94 Standard Specification for Ready-Mixed Concrete.
9. ASTM C109 Standard Test Method for Compressive Strength of Hydraulic Cement Mortars.
10. ASTM C136 Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.
11. ASTM C150 Standard Specification for Portland.
12. ASTM C171 Standard Specification for Sheet Materials for Curing Concrete.
13. ASTM C219 Standard Terminology Relating to Hydraulic and Other Inorganic Cements.
14. ASTM C309 Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete.
15. ASTM C330 Standard Specification for Lightweight Aggregates for Structural Concrete.
16. ASTM C566 Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying.
17. ASTM C881 Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete.
18. ASTM C1059 Standard Specification for Latex Agents for Bonding Fresh To Hardened Concrete.
19. ASTM C1077 Standard Practice for Agencies Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Testing Agency Evaluation.

20. ASTM C1315 Standard Specification for Liquid Membrane-Forming Compounds Having Special Properties for Curing and Sealing Concrete.
21. ASTM D1751 Standard Specification for Preformed Expansion Joint Filler for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types).
22. ASTM D1752 Standard Specification for Preformed Sponge Rubber, Cork and Recycled PVC Expansion Joint Fillers for Concrete Paving and Structural Construction.
23. ASTM D7957 Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement.
24. ASTM E329 Standard Specification for Agencies Engaged in Construction Inspection, Testing, or Special Inspection.
25. ASTM E1155 Standard Test Method for Determining FF Floor Flatness and FL Floor Levelness Numbers.
26. ASTM E1643 Standard Practice for Selection, Design, Installation, and Inspection of Water Vapor Retarders Used in Contact with Earth or Granular Fill Under Concrete Slabs.
27. ASTM E1745 Standard Specification for Plastic Water Vapor Retarders Used in Contact with Soil or Granular Fill under Concrete Slabs.

D. American Institute of Steel Construction (AISC)
1. ANSI/AISC 303 Code of Standard Practice for Steel Buildings and Bridges.

E. American Welding Society (AWS)
1. AWS D1.1 Structural Welding Code - Steel.
2. AWS D1.4 Structural Welding Code - Steel Reinforcing Bars.

F. Concrete Reinforcing Steel Institute (CRSI)
1. Manual of Standard Practice.
2. CRSI RB4.1 Supports for Reinforcement Used in Concrete.

G. Corp of Engineers (CE)
1. CRD-C 572 Corps of Engineers Specifications for Polyvinylchoride Waterstops.

H. National Institute of Standards and Technology (NIST)
1. PS 1-07 Structural Plywood, Voluntary Product Standard.

1.4 PREINSTALLATION MEETINGS

A. Preinstallation Conference: Conduct conference at project site.

B. Include relevant items from this specification in agenda for concrete mix development preconstruction meeting.
1. Before submitting design mixtures and repair procedures, review concrete design mixture and examine procedures for ensuring quality of concrete materials. Require representatives of each entity directly concerned with cast-in-place concrete to attend, including the following:
    a. Contractor's superintendent.
    b. Independent Testing Agency responsible for concrete design mixtures.
    c. Ready-mix concrete manufacturer.
    d. Concrete subcontractor, if applicable.

2. Review special inspection and testing and inspecting agency procedures for field quality control (QC), concrete finishes and finishing, cold- and hot-weather concreting procedures, curing procedures, construction contraction and isolation joints, and joint-filler strips, semirigid joint fillers, forms and form removal limitations, vapor-retarder installation, anchor rod and anchorage device installation tolerances, steel reinforcement installation, methods for achieving specified floor and slab flatness and levelness, concrete repair procedures, and concrete protection.

1.5 ACTION SUBMITTALS

A. Product Data: For each type of product.
   1. Form release agents.
   2. Bonding agents.
   3. Grout.
   4. Repair materials.
   5. Curing materials.
   6. Waterstops, vapor retarders.
   7. Regroutable hoses.
   8. Joints and joint sealant.
   9. Reinforcement and reinforcement supports.
   10. Post-installed anchors, mechanical and adhesive.

B. Proposed concrete delivery, placing, finishing and curing methods, and equipment information.

C. Proposed concrete curing and protection procedures for cold and hot weather concreting.

D. Manufacturer product data and installation procedures for all other products to be used in concrete construction.

E. Design Mixtures: Refer to Section 033100 “Structural Concrete Materials”.

F. Prequalify repair procedures and materials.

G. Steel Reinforcement Shop Drawings: Placing drawings that detail fabrication, bending, and placement. Include bar sizes, lengths, material, grade, bar schedules, stirrup spacing, bent bar diagrams, bar arrangement, splices and laps, mechanical connections, tie spacing, hoop spacing, and supports for concrete reinforcement. Reinforcement placing drawings shall be prepared in accordance with ACI SP-066. Lap lengths, bar development lengths, and concrete cover shall be in accordance with ACI 318 unless shown otherwise in the Agreement Drawings.

H. Construction Joint Layout:
   1. Indicate proposed construction joints required to construct the structure.
   2. Layout of waterstops.
   3. Layout of regroutable hoses and junction boxes with labeling system to identify each hose and its location as well as fixation and termination of hoses.
   4. Location of construction joints is subject to approval of the Designer.

I. Samples: For waterstops, regroutable hoses, reinforcement supports, vapor retarders.

1.6 INFORMATIONAL SUBMITTALS

A. Qualification Data: For installer, manufacturer, formwork engineer, and Testing Agency.

B. Welding certificates.

C. Material Certificates: For each of the following, signed by manufacturers:
1. Form materials and form-release agents.
2. Steel reinforcement and accessories.
3. Waterstops.
4. Curing compounds.
5. Floor and slab treatments.
6. Bonding agents.
7. Adhesives.
8. Vapor retarders.
9. Semirigid joint filler.
10. Joint-filler strips.
11. Repair materials.

D. Formwork Shop Drawings: Prepared by or under the supervision of the formwork engineer, detailing fabrication, assembly, and support of formwork.
1. Shoring and reshoring: Indicate proposed schedule and sequence of stripping formwork, shoring removal, and reshoring installation and removal.

E. Floor surface flatness and levelness measurements indicating compliance with specified tolerances.

F. Field quality-control reports.

G. Minutes of preinstallation conference.

1.7 QUALITY ASSURANCE

A. Installer Qualifications: A qualified installer shall employ site based personnel qualified as ACI-certified flatwork technician and finisher and a supervisor who is an ACI-certified concrete flatwork technician.

B. Ready-mixed concrete manufacturer qualifications: Refer to Section 033100 “Structural Concrete Materials”.

C. Formwork Engineer: Registered Professional Engineer licensed in the State of Michigan.

D. Testing Agency Qualifications: An independent agency, acceptable to authorities having jurisdiction, qualified according to ASTM C1077 and ASTM E329 for testing indicated.
1. Personnel conducting field tests shall be qualified as ACI concrete field testing technician, grade 1, according to ACI CP-1 or an equivalent certification program.
2. Personnel performing laboratory tests shall be ACI-certified concrete strength testing technician and concrete laboratory testing technician, grade I. Testing Agency laboratory supervisor shall be an ACI-certified concrete laboratory testing technician, grade II.

E. Welding Qualifications: Qualify procedures and personnel according to AWS D1.4.

1.8 PRECONSTRUCTION TESTING

A. Preconstruction Testing Service: Engage a qualified Testing Agency to perform preconstruction testing on concrete mixtures.

1.9 DELIVERY, STORAGE, AND HANDLING

A. Steel Reinforcement: Deliver, store, and handle steel reinforcement to prevent bending and damage. Avoid damaging coatings on steel reinforcement. Reinforcing bars shall be shipped in bundles clearly identified in accordance with bar bending details and lists. Each bundle shall have a metal tag identifying the purchase order number, project number, name and number of the structure, number of pieces, and material type. All material within one bundle shall be of the same grade and shall be for the same structure.

B. Waterstops: Store waterstops under cover to protect from moisture, sunlight, dirt, oil, and other contaminants.

1.10 FIELD CONDITIONS

A. Cold-Weather Placement: Comply with ACI 306R and ACI 306.1 and as follows. Protect concrete work from physical damage or reduced strength that could be caused by frost, freezing actions, or low temperatures.
   1. When average high and low temperature is expected to fall below 40 deg F for three successive days, maintain delivered concrete mixture temperature within the temperature range required by ACI 301.
   2. Do not use frozen materials or materials containing ice or snow. Do not place concrete on frozen subgrade or on subgrade containing frozen materials.
   3. Do not use calcium chloride, salt, or other materials containing antifreeze agents or chemical accelerators unless otherwise specified and approved in mixture designs.
   4. Do not place concrete during rain or snow unless proper protection is provided against rain or snow entering the concrete from the time of handling to the final set.
   5. During freezing weather, protect all cured foundations and footings from frost and consequent heaving.
   6. If heat is provided by fired equipment, care shall be taken to prevent the concrete from drying out, and ventilation shall be provided to avoid the risk of health hazards and the carbonation of young concrete. When heating equipment is used, control temperature through the use of thermostats to ensure temperature does not rise above 80 deg F.
   7. To avoid cracking of the concrete due to sudden temperature changes near the end of the curing period, do not completely remove the protection until the concrete has cooled to the temperature differential indicated in ACI 306R.

B. Hot-Weather Placement: Comply with ACI 301, ACI 305R and ACI 305.1, and as follows:
   1. Maintain concrete temperature below 95 deg F at time of placement. Chilled mixing water or chopped ice may be used to control temperature, provided water equivalent of ice is calculated to total amount of mixing water. Using liquid nitrogen to cool concrete is Contractor's option.

2. Fog-spray forms, steel reinforcement, and subgrade just before placing concrete. Keep subgrade uniformly moist without standing water, soft spots, or dry areas.

C. The determination and recording of air and concrete temperature to check compliance with requirements shall be the responsibility of the Contractor. Monitor and record the temperature of curing concrete.

PART 2 - PRODUCTS

2.1 CONCRETE, GENERAL

A. ACI Publications: Comply with the following unless modified by requirements in the Agreement and Exhibits:
1. ACI 301.
2. ACI 117.

2.2 FORM-FACING MATERIALS

A. Smooth-Formed Finished Concrete: Form-facing panels that provide continuous, true, and smooth concrete surfaces. Furnish in largest practicable sizes to minimize number of joints.
1. Exterior-grade plywood panels, suitable for concrete forms, complying with PS 1-07, and as follows:
a. Medium-density overlay, class 1 or better; mill-release agent treated and edge sealed.

B. Rough-Formed Finished Concrete: Plywood, lumber, metal, or another approved material. Provide lumber dressed on at least two edges and one side for tight fit.

C. Forms for Cylindrical Columns, Pedestals, and Supports: Metal, glass-fiber-reinforced plastic, paper, or fiber tubes that produce surfaces with gradual or abrupt irregularities not exceeding specified formwork surface class. Provide units with sufficient wall thickness to resist plastic concrete loads without detrimental deformation.

D. Chamfer Strips: Wood, metal, PVC, or rubber strips, 1 by 1 inch, minimum.
1. All re-entrant corners shall have a 3/4 inch fillet.

E. Form-Release Agent: Commercially formulated form-release agent that does not bond with, stain, or adversely affect concrete surfaces and does not impair subsequent treatments of concrete surfaces.
1. Formulate form-release agent with rust inhibitor for steel form-facing materials.

F. Form Ties: Factory-fabricated, removable or snap-off glass-fiber-reinforced plastic or metal form ties designed to resist lateral pressure of fresh concrete on forms and to prevent spalling of concrete on removal.
1. Furnish units that leave no corrodible metal closer than 3 inches to the plane of exposed concrete surface.
2. Furnish ties that, when removed, leave holes no larger than 1 inch in diameter in concrete surface.

3. Furnish ties with integral water-barrier plates to walls indicated to receive dampproofing or waterproofing.

2.3 STEEL REINFORCEMENT

A. Reinforcing Bars: ASTM A615, grade 60, deformed.

B. Low-Alloy-Steel Reinforcing Bars: ASTM A706, deformed. Ship all weldable reinforcing clearly tagged.

C. Galvanized Reinforcing Bars: ASTM A615 grade 60, ASTM A706 deformed bars, ASTM A767 class I zinc coated after fabrication and bending.

D. Steel Bar Mats: ASTM A184, fabricated from ASTM A615 grade 60 ASTM A706, deformed bars, assembled with clips.

E. Plain-Steel Wire: ASTM A1064 galvanized, grade 65.

F. Deformed-Steel Wire: ASTM A1064 grade 80 for precast concrete tunnel lining and grade 65 for cast-in-place concrete.

G. Plain-Steel Welded-Wire Reinforcement: ASTM A1064 plain, fabricated from as-drawn steel wire into flat sheets, grade 65.

H. Deformed-Steel Welded-Wire Reinforcement: ASTM A1064 flat sheet, grade 65.

I. Galvanized-Steel Welded-Wire Reinforcement: ASTM A1064, plain, fabricated from galvanized-steel wire into flat sheets, grade 65.

J. Glass fiber-glass reinforced plastic (GFRP) reinforcing per ASTM D7957. FRP reinforcing consisting of composite of cross-linking polymer resin matrix reinforced by continuous glass filaments in a reinforcement to matrix ratio of 70/30 percent by weight:
   1. FRP reinforcing manufactured by pultrusion process.
   2. Minimum ultimate tensile strength: 140,000 psi.
   3. Tensile modulus: 7,860,000 psi.
   4. For support of FRP reinforcing, use all plastic chairs and bolsters.

2.4 REINFORCEMENT ACCESSORIES

A. Joint Dowel Bars: ASTM A615 grade 60, plain-steel bars, cut true to length with ends square and free of burrs, galvanized.

B. Zinc Repair Material: ASTM A780.

C. Bar Supports: CRSI RB4.1 “Supports for Reinforcement used in Concrete”. Bolsters, chairs, spacers, and other devices for spacing, supporting, and fastening reinforcing bars and welded-wire reinforcement in place. Chairs and side form spacers shall be non-metallic, and internal spacers and supports shall be made from reinforcement bars or steel rods. If precast concrete chairs or side form spacers are used, they shall have the same properties as the concrete being

poured. Manufacture bar supports from plastic, or precast concrete according to CRSI's "Manual of Standard Practice," of greater compressive strength than concrete.

D. Bar Supports for GFRP Reinforcing: Bar supports for FRP shall consist of all plastic chairs and bolsters. Secure FRP reinforcing with plastic ties only.

E. Reinforcement tie wire hall be 16-gauge, cold-drawn, black-annealed steel wire conforming to ASTM A1064.

F. Mechanical Splices:
   1. Where shown in the Agreement Drawings, mechanical splices shall be full mechanical connections capable of developing in tension or compression, as required, to at least 120% of the specified yield strength of the bar.

2.5 CONCRETE MATERIALS

A. Refer to Section 033100 “Structural Concrete Materials” for concrete material requirements.

2.6 WATERSTOPS

A. Flexible PVC Waterstops: CE CRD-C 572, with factory-installed metal eyelets, for embedding in concrete to prevent passage of fluids through joints. Factory fabricate corners, intersections, and directional changes.
   1. Profile: Ribbed with center bulb as indicated on Agreement Drawings.
   2. Dimensions: 4 inches by 3/16 inch.

B. Self-Expanding Rubber Strip Waterstops: Manufactured rectangular or trapezoidal strip, bentonite-free hydrophilic polymer-modified chloroprene rubber, for adhesive bonding to concrete, 1-1/4 by 1-1/4 inch.

2.7 REGROUTABLE HOSES

A. Regroutable Hose: SikaFuko VT2 or Company-approved equal.
   1. Minimum 3/4-inch outside diameter, consisting of a solid core with lateral openings covered by neoprene strips and the entire system wrapped with a wide mesh, suitable for injection with resin grouts.
   2. Equipped with color-coded injection and ventilation ends, closure plugs and anchoring system.

B. Junction Box: Heavy-duty plastic box with removable cover compatible with the regroutable hose system and of sufficient size to accommodate injection and ventilation ends of hoses.

2.8 VAPOR RETARDERS

A. Sheet Vapor Retarder: ASTM E1745, class A, except with maximum water-vapor permeance of 0.01 perms. Include manufacturer's recommended adhesive or pressure-sensitive joint tape.

2.9 FLOOR AND SLAB TREATMENTS

A. Slip-Resistive Aluminum Granule Finish: Factory-graded, packaged, rustproof, nonglazing, abrasive aggregate of not less than 95 percent fused aluminum-oxide granules.

2.10 CURING MATERIALS

A. Evaporation Retarder: Waterborne, monomolecular film forming, manufactured for application to fresh concrete.

B. Absorptive Cover: AASHTO M 182, class 2, burlap cloth made from jute or kenaf, weighing approximately 9 oz./sq. yd. when dry.

C. Moisture-Retaining Cover: ASTM C171, polyethylene film or white burlap-polyethylene sheet.

D. Water: Potable.

E. Clear, Waterborne, Membrane-Forming Curing Compound: ASTM C309, type 1, class B, non-dissipating certified by curing compound manufacturer to not interfere with bonding of floor covering.

F. Clear, Waterborne, Membrane-Forming Curing and Sealing Compound: ASTM C1315, type 1, class A.

2.11 RELATED MATERIALS

A. Expansion and Isolation-Joint-Filler Strips: ASTM D1751, asphalt-saturated cellulosic fiber or ASTM D1752 type 1, sponge rubber.

B. Bonding Agent: ASTM C1059 type II, nonredispersible, acrylic emulsion or styrene butadiene.

C. Epoxy Bonding Adhesive: ASTM C881, two-component epoxy resin, capable of humid curing and bonding to damp surfaces, of class suitable for application temperature and of grade to suit requirements, and as follows:
   1. Types IV and V, load bearing, for bonding hardened or freshly mixed concrete to hardened concrete.

D. Reglets: Fabricate reglets of not less than 0.022-inch-thick, galvanized-steel sheet. Temporarily fill or cover face opening of reglet to prevent intrusion of concrete or debris.

E. Dovetail Anchor Slots: Hot-dip galvanized-steel sheet, not less than 0.034 inch thick, with bent tab anchors. Temporarily fill or cover face opening of slots to prevent intrusion of concrete or debris.

F. Post-installed Anchors:
   1. Mechanical Anchors: ICC-ES approved expansion or sleeve anchors meeting provisions of ACI 355.2 and ICC-ES acceptance criteria 193. Type and manufacturer as indicated on Agreement Drawings.

2. Adhesive Anchors: ICC-ES approved adhesive anchorage systems meeting provisions of ACI 355.4 and ICC-ES acceptance criteria 308. Type and manufacturer as indicated on Agreement Drawings.

2.12 REPAIR MATERIALS

A. General
   1. Repair materials shall achieve the same design life as the parent concrete being repaired. Refer to Section 033100 “Structural Concrete Materials”.

B. Repair Underlayment: Cement-based, polymer-modified, self-leveling product that can be applied in thicknesses from 1/8 inch and that can be feathered at edges to match adjacent floor elevations.
   1. Cement Binder: ASTM C150 Portland cement or hydraulic or blended hydraulic cement as defined in ASTM C219.
   2. Primer: Product of underlayment manufacturer recommended for substrate, conditions, and application.
   3. Aggregate: Well-graded, washed gravel, 1/8 to 1/4 inch or coarse sand as recommended by underlayment manufacturer.
   4. Compressive Strength: Not less than 5000 psi at 28 days when tested according to ASTM C109.

C. Repair Overlayment: Cement-based, polymer-modified, self-leveling product that can be applied in thicknesses from 1/4 inch and that can be filled in over a scarified surface to match adjacent floor elevations.
   1. Cement Binder: ASTM C150 Portland cement or hydraulic or blended hydraulic cement as defined in ASTM C219.
   2. Primer: Product of topping manufacturer recommended for substrate, conditions, and application.
   3. Aggregate: Well-graded, washed gravel, 1/8 to 1/4 inch or coarse sand as recommended by topping manufacturer.
   4. Compressive Strength: Not less than 5000 psi at 28 days when tested according to ASTM C109.

2.13 CONCRETE MIXTURES, GENERAL

A. Refer to Section 033100 “Structural Concrete Materials” for concrete mix requirements.

2.14 FABRICATING REINFORCEMENT

A. Fabricate steel reinforcement according to CRSI's "Manual of Standard Practice."

2.15 CONCRETE MIXING

A. Refer to Section 033100 “Structural Concrete Materials”.

2.16 SOURCE QUALITY CONTROL

A. Concrete Materials Only: In accordance with Section 033100 “Structural Concrete Materials”.

B. At a minimum, include the following items in the Inspection and Test Plan:
   1. Surveillance:
      a. Observe batch plant facilities, scales, and truck mixers and verify they meet requirements of ASTM C94.
   2. Review:
      a. Batch plant quality assurance/QC plan.
   3. Verification:
      a. Verify concrete producer conducts aggregate moisture content tests per ASTM C566.
      b. Verify concrete producer grades aggregate in accordance with ASTM C136 and in compliance with ASTM C33 and ASTM C 330.
   4. Witness Point:
      a. Not used.
   5. Hold Point:
      a. Verify batch plant storage complies with ASTM C94.

PART 3 - EXECUTION

3.1 FORMWORK INSTALLATION

A. Design, erect, shore, brace, and maintain formwork, according to ACI 301, to support vertical, lateral, static, and dynamic loads, and construction loads that might be applied, until structure can support such loads.

B. Construct formwork so concrete members and structures are of size, shape, alignment, elevation, and position indicated, within tolerance limits of ACI 117.

C. Limit concrete surface irregularities, designated by ACI 347.3R as abrupt or gradual, as follows:
   1. Class A, 1/8 inch for smooth-formed finished surfaces.
   2. Class B, 1/4 inch for rough-formed finished surfaces.

D. Construct forms tight enough to prevent loss of concrete mortar.

E. Construct forms for easy removal without hammering or prying against concrete surfaces. Provide crush or wrecking plates where stripping may damage cast-concrete surfaces. Provide top forms for inclined surfaces steeper than 1.5 horizontal to 1 vertical:
   1. Install keyways, reglets, recesses, and the like, for easy removal.
   2. Do not use rust-stained steel form-facing material.

F. Set edge forms, bulkheads, and intermediate screed strips for slabs to achieve required elevations and slopes in finished concrete surfaces. Provide and secure units to support screed strips; use strike-off templates or compacting-type screeds.

G. Provide temporary openings for cleanouts and inspection ports where interior area of formwork is inaccessible. Close openings with panels tightly fitted to forms and securely braced to prevent loss of concrete mortar. Locate temporary openings in forms at inconspicuous locations.

H. Chamfer exterior corners and edges of permanently exposed concrete.

I. Form openings, chases, offsets, sinkages, keyways, reglets, blocking, screeds, and bulkheads required in the work. Determine sizes and locations from trades providing such items.

J. Clean forms and adjacent surfaces to receive concrete. Remove chips, wood, sawdust, dirt, snow, ice and other debris just before placing concrete.

K. Retighten forms and bracing before placing concrete, as required, to prevent mortar leaks and maintain proper alignment.

L. Coat contact surfaces of forms with form-release agent, according to manufacturer's written instructions, before placing reinforcement.

M. Construct forms for exposed concrete of materials in accordance with the requirements of ACI 347R and ACI SP-004.

N. On exposed surfaces, horizontal joints shall be matched throughout the structure, and vertical joints shall be set square.

3.2 EMBEDDED ITEM INSTALLATION

A. All delivered embedded items shall be tagged. Tags shall be made of durable materials and marked in a legible manner. At least one tag shall be attached by wire to each bundle.

B. Place and secure anchorage devices and other embedded items required for adjoining work that is attached to or supported by cast-in-place concrete. Use setting drawings, templates, diagrams, instructions, and directions furnished with items to be embedded. Unless otherwise shown in the Agreement Drawings or specified by the Company, the locations of embedded items shall not vary from the dimensions shown in the Agreement Drawings by more than the tolerances listed in ACI 318.
   1. Install anchor rods, accurately located, to elevations required and complying with tolerances in Section 7.5 of AISC 303.
   2. Install reglets to receive waterproofing and to receive through-wall flashings in outer face of concrete frame at exterior walls, where flashing is shown at lintels, shelf angles, and other conditions.
   3. Install dovetail anchor slots in concrete structures as indicated.

C. Embedded horizontal plates shall have inspection holes or vent holes as required to ensure full bond of concrete to the underside of the plate. Inspect plates for voids, and repair all voids.

D. Welding of and to embedded steel shall conform to the requirements of AWS D1.1. Welding shall be performed only by the AWS-certified fabricators (CWF). Refer to Section 051200 “Structural Steel Framing” for the performance requirements for the inspection and testing of welds.

E. Sleeves, conduits, and other pipes passing through floors or walls shall be sized and located as indicated in the Agreement Drawings.

3.3 REMOVING AND REUSING FORMS

A. Subject to Company review, forms may be reused provided they are clean and in sound condition, free from all foreign matter, and repairs have been made to all surfaces where forms have been split, frayed, delaminated or where form facing material has been otherwise damaged in a manner that would affect finished concrete integrity or finish. Reuse of formwork and falsework shall be subject to the requirements of ACI 347R and ACI SP-004.

B. General: Formwork for sides of beams, walls, columns, and similar parts of the work that does not support weight of concrete may be removed after cumulatively curing at not less than 50 deg F for 24 hours after placing concrete. Concrete has to be hard enough to not be damaged by form-removal operations, and curing and protection operations need to be maintained:
   1. Leave formwork for beam soffits, joists, slabs, and other structural elements that support weight of concrete in place until concrete has achieved at least 70 percent of its 28-day design compressive strength.
   2. Remove forms only if shores have been arranged to permit removal of forms without loosening or disturbing shores.

C. Clean and repair surfaces of forms to be reused in the work. Split, frayed, delaminated, or otherwise damaged form-facing material are not acceptable for exposed surfaces. Apply new form-release agent.

D. When forms are reused, clean surfaces, remove fins and laitance, and tighten to close joints. Align and secure joints to avoid offsets. Do not use patched forms for exposed concrete surfaces unless approved by Designer.

3.4 EARLY LOADING OF EQUIPMENT ONTO STRUCTURE

A. Early loading of equipment onto the structure is permitted if it can be demonstrated through compressive strength testing that the concrete has achieved sufficient strength and the Company gives approval. To ensure the project has enough cylinders to complete the required testing, cast extra cylinders during placement. If these conditions are not satisfied, loading of equipment onto the structure shall be permitted only after the concrete has attained the specified 28-day compressive strength. Concrete shall not be loaded prior to the curing period specified as formwork removal criteria, even if strength has been demonstrated.

3.5 VAPOR-RETARDER INSTALLATION

A. Sheet Vapor Retarders: Place, protect, and repair sheet vapor retarder according to ASTM E1643 and manufacturer's written instructions.
   1. Lap joints 6 inches and seal with manufacturer's recommended tape.

B. Bituminous Vapor Retarders: Place, protect, and repair bituminous vapor retarder according to manufacturer's written instructions.

3.6 STEEL REINFORCEMENT INSTALLATION

A. General: Comply with CRSI's "Manual of Standard Practice" for fabricating, placing, and supporting reinforcement:
   1. Comply with ACI 117 for reinforcement placement tolerances.
   2. Do not cut or puncture vapor retarder. Repair damage and reseal vapor retarder before placing concrete.

B. Store steel reinforcement on platforms, skids, or other supports so that reinforcement does not touch soil or standing water. Store steel reinforcement neatly and clearly marked to facilitate inspection.

C. Clean reinforcement of loose rust and mill scale, earth, ice, and other foreign materials that reduce bond to concrete.

D. Accurately position, support, and secure reinforcement against displacement. Locate and support reinforcement with bar supports to maintain minimum concrete cover. Do not tack weld crossing reinforcing bars. Use wire ties to secure all bar intersections or where the product of the length and width of bar intersection spacing exceeds 120 square inches. If the product of the length and the width of spacing does not exceed 120 square inches, tie alternate intersections. Do not weld.

E. Tie bar laps near each end of the lap. Provide a clear distance from the reinforcement to the concrete surface by no more than 3/8 inch from the dimensions shown on the plans. Provide concrete clear cover over the top reinforcement at least equal to the dimensions shown on the plans.
   1. Weld reinforcing bars according to AWS D1.4 where indicated.

F. Set wire ties with ends directed into concrete, not toward exposed concrete surfaces.

G. Install welded-wire reinforcement in longest practicable lengths on bar supports spaced to minimize sagging. Lap edges and ends of adjoining sheets at least one mesh spacing. Offset laps of adjoining sheet widths to prevent continuous laps in either direction. Lace overlaps with wire.

H. Zinc-Coated Reinforcement: Repair cut and damaged zinc coatings with zinc repair material according to ASTM A780. Use galvanized-steel wire ties to fasten zinc-coated steel reinforcement.

I. Do not bend reinforcing bars in the field except where indicated in the Agreement Drawings. Field bending shall be done cold using a mandrel and applying slow, steady pressure. Bend bars to radii requirements per ACI. Replace bars that develop cracks or splits.

J. Bars with bends and kinks not shown in the Agreement Drawings shall not be used. Do not straighten or rebend reinforcement.

K. Where reinforcement is left exposed for lapping with future reinforcement, protect the exposed portions as shown in the reinforcement placing shop drawings or as directed by the Company. Use wooden templates to ensure this rebar is placed in the correct location and will satisfy cover requirements of future pours.

L. Where conduit, pipe inserts, sleeves, or other embedded inserts interfere with placing the reinforcement, make adjustments as directed by the Company before the concrete is poured. Do not cut reinforcement to clear obstructions.

M. Install post-installed dowels and other inserts that are drilled and grouted into hardened concrete as indicated in the Agreement Drawings. Hole diameter, length, and preparation shall be according to the Agreement Drawings and the grout manufacturer's recommendations. Dry fit-up of all drilled dowels and inserts shall be inspected by the Company prior to grouting.
1. Make every effort to ensure that reinforcement is not damaged. Locate rebar by scanning or other nondestructive method and mark on the concrete surface prior to drilling. Do not use drilling equipment or methods that could damage rebar (e.g., diamond-tip drill bits) unless permitted in the Agreement Drawings. Do not use drilling equipment or methods that could cause cracking of the concrete. Cure concrete for a minimum of 28 days before being drilled. If fast-curing concrete has been used, the cure time may be reduced to a minimum of seven days, provided tests indicate the concrete has reached 100% of the design strength shown in the Agreement Drawings.

3.7 JOINTS

A. General: Construct joints true to line with faces perpendicular to surface plane of concrete.

B. Construction Joints: Install so strength and appearance of concrete are not impaired, at locations indicated or as approved by Designer.
1. Place joints perpendicular to main reinforcement. Continue reinforcement across construction joints unless otherwise indicated. Do not continue reinforcement through sides of strip placements of floors and slabs.
2. Form keyed joints as indicated. Embed keys at least 1-1/2 inches into concrete.
3. Locate joints for beams, slabs, joists, and girders in the middle third of spans. Offset joints in girders a minimum distance of twice the beam width from a beam-girder intersection.
4. Locate horizontal joints in walls and columns at underside of floors, slabs, beams, and girders and at the top of footings or floor slabs.
5. Space vertical joints in walls as indicated. Locate joints beside piers integral with walls, near corners, and in concealed locations where possible.
6. Do not place additional concrete loading recently poured concrete until the concrete cures for at least three days and attains at least 70 percent of its 28-day flexural or compressive design strength.

C. Contraction Joints in Slabs-on-Grade: Form weakened-plane contraction joints, sectioning concrete into areas as indicated. Construct contraction joints for a depth equal to at least one-fourth of concrete thickness as follows:
1. Sawed Joints: Form contraction joints with power saws equipped with shatterproof abrasive or diamond-rimmed blades. Cut 1/8-inch-wide joints into concrete when cutting action does not tear, abrade, or otherwise damage surface and before concrete develops random contraction cracks.

D. Isolation Joints in Slabs-on-Grade: After removing formwork, install joint-filler strips at slab junctions with vertical surfaces, such as column pedestals, foundation walls, grade beams, and other locations, as indicated.

1. Extend joint-filler strips full width and depth of joint, terminating flush with finished concrete surface unless otherwise indicated.
2. Terminate full-width joint-filler strips not less than 1/2 inch or more than 1 inch below finished concrete surface where joint sealants are indicated.
3. Install joint-filler strips in lengths as long as practicable. Where more than one length is required, lace or clip sections together.

E. Doweled Joints: Install dowel bars and support assemblies at joints where indicated. Lubricate or asphalt coat one-half of dowel length to prevent concrete bonding to one side of joint.

3.8 WATERSTOP INSTALLATION

A. Flexible Waterstops: Install in construction joints and at other joints indicated to form a continuous diaphragm. Install in longest lengths practicable. Support and protect exposed waterstops during progress of the work. Field fabricate joints in waterstops according to manufacturer's written instructions.

B. Self-Expanding Strip Waterstops: Install in construction joints and at other locations indicated, according to manufacturer's written instructions, adhesive bonding, mechanically fastening, and firmly pressing into place. Install in longest lengths practicable.

3.9 REGROUTABLE HOSE INSTALLATION

A. Install regroutable hoses as shown on the Agreement Drawings.

B. Fasten regroutable hose to hold the hose in place during application of concrete.

C. Install junction boxes nearby to receive and hold regroutable injection hoses and ventilation ends of hoses.

D. Protect junction boxes and the hoses associated with them from damage during concrete pours.

E. Provide a labeling system for regroutable hoses and maintain written records of their locations for inclusion on the Record Drawings.

F. If leak sealing is required, follow requirements of Section 310179 “Sealing Leaks”.

3.10 PREPARATION FOR CONCRETE PLACEMENT

A. Prior to placing concrete, remove all debris and thoroughly dampen the surfaces that may be in contact with the concrete to be placed.

B. Use compressed air from an air compressor to blow out construction debris and dirt at the bottom of members to be placed such as walls, beams, and columns, prior to final placement of forms that may obscure any joint. Ensure that all debris, such as concrete particles, saw dust, loose tie wire, bar tags, tape, trash and dirt, have been thoroughly removed.

C. Clean all surfaces of forms and embedded materials that have become encrusted with dried mortar or grout from concrete previously placed of all such mortar or grout before the surrounding or adjacent concrete is placed.

D. Immediately before placing concrete, all surfaces upon or against which the concrete is to be placed shall be free from snow, ice, standing water, mud, debris, or loose materials.

E. No concrete shall be placed when form surfaces that may be in contact with the concrete, reinforcement, embedded items or sub-base is less than 32 deg F. When the mean daily outdoor temperature is less than 40 deg F, the temperature of the concrete shall be maintained between 50 deg F and 70 deg F for the required curing period. When necessary, make arrangements for heating, covering, insulating, or housing the concrete work in advance of placement which shall be adequate to maintain the required temperature without injury as a result of concentration of heat. Do not use combustion heaters during the first twenty four (24) hours unless precautions are taken to prevent exposure of the concrete to exhaust gases which contain carbon dioxide.

F. Do not place concrete against forms exposed to heating unless the temperature of the forms is first cooled to less than or equal to ninety degrees Fahrenheit (≤90°F).

3.11 CONCRETE PLACEMENT

A. Placement shall conform to ACI 301, ACI 304R, ACI 306.1, ACI 305.1, and ACI 309R. No concrete shall be placed in water except with the written permission of the Designer. The surfaces of absorptive materials against or upon which concrete is to be placed shall be moistened thoroughly so that moisture will not be drawn from the freshly placed concrete. Place concrete with equipment that will prevent segregation or loss of ingredients. The stream of concrete shall not be allowed to separate by permitting it to fall freely more than 6 feet over rods, spacers or other embedded materials.

B. Do not use re-tempered concrete and concrete that has been partially hardened or contaminated by foreign material.

C. Before test sampling and placing concrete, water may be added at project site, subject to limitations of ACI 301.
   1. Do not add water to concrete after adding high-range water-reducing admixtures to mixture.

D. Deposit concrete continuously in one layer or in horizontal layers of such thickness that no new concrete is placed on concrete that has hardened enough to cause seams or planes of weakness. If a section cannot be placed continuously, provide construction joints as indicated. Deposit concrete to avoid segregation.
   1. Deposit concrete in horizontal layers of depth not to exceed formwork design pressures and in a manner to avoid inclined construction joints.
   2. Consolidate placed concrete with mechanical vibrating equipment according to ACI 301. Concrete may be consolidated using hand methods if the use of vibratory equipment is not possible.
   3. Do not use vibrators to transport concrete inside forms. Insert and withdraw vibrators vertically at uniformly spaced locations to rapidly penetrate placed layer and at least 6 inches into preceding layer. Do not insert vibrators into lower layers of concrete that have begun to lose plasticity. At each insertion, limit duration of vibration to time necessary to

consolidate concrete and complete embedment of reinforcement and other embedded items without causing mixture constituents to segregate.

E. Deposit and consolidate concrete for floors and slabs in a continuous operation, within limits of construction joints, until placement of a panel or section is complete.
   1. Consolidate concrete during placement operations, so concrete is thoroughly worked around reinforcement and other embedded items and into corners.
   2. Maintain reinforcement in position on chairs during concrete placement.
   3. Screed slab surfaces with a straightedge and strike off to correct elevations.
   4. Slope surfaces uniformly to drains where required.
   5. Begin initial floating using bull floats or darbies to form a uniform and open-textured surface plane, before excess bleedwater appears on the surface. Do not further disturb slab surfaces before starting finishing operations.

F. Place concrete to avoid segregation of the materials and the displacement of the reinforcement.

G. Do not drop concrete more than five feet unless confined by closed chutes or pipes. Take care to fill each part of the form by depositing the concrete as near final position as possible. The coarse aggregate shall be worked back from the forms and worked around the reinforcement without displacing the bars. After initial set of the concrete, the forms shall not be jarred and strain shall not be placed on the ends of projecting reinforcement.

H. Where steep slopes are required, equip chutes with baffle boards or use short lengths that reverse the direction of movement.

I. Do not pump concrete through aluminum alloy pipe. When concrete is placed by pumping, no excess grout or mortar used to lubricate the delivery lines shall enter the forms. Discard concrete that has come into contact with washout.

J. Methods and procedures of tremie concreting shall be in accordance with the requirements of ACI 304R.

K. Keep all chutes, troughs, and pipes clean and free from coatings of hardened concrete.

3.12 CONSOLIDATION

A. Perform thorough consolidation of concrete in accordance with the requirements of ACI 309R immediately after deposition to produce a dense, homogeneous structure free of voids, honeycombing, weak planes, or cold joints. The concrete shall be well bonded to all steel reinforcement, anchors, waterstops, and embedded parts. Thoroughly work the concrete around the reinforcing steel, around embedded items and into corners of forms. Supplement vibration by spading, rodding, or forking to eliminate all honeycomb and voids around embedded items.

B. Use 2-1/2 inch diameter “high cycle” vibrators with a frequency under load of 8,000 to 10,400 vibrations per minute (vpm) for consolidating concrete. Concrete vibrators of lesser capacity are unacceptable for use in any part of the construction. Provide at least one standby concrete vibrator ready for use for every two concrete vibrators in use during a concrete placement.

C. Insert the vibrator vertically, allowing it to penetrate rapidly to the bottom of the lift and at least 6 inches into the previous lift. Hold the vibrator at the bottom of lift for 5 to 15 seconds. Remove the vibrator at a rate of about 3 inches per second.

D. Insert the vibrator so that the fields of action overlap. The field of action is approximately eight times the vibrator's head diameter. Vibrators shall not come into contact with reinforcements.

E. Stop vibration when the concrete surface takes a sheen and large air bubbles no longer escape.

F. Do not use a vibrator to move concrete horizontally.

G. Use of external vibration shall not be permitted without the prior approval of the Company.

3.13 FINISHING FORMED SURFACES

A. Finish requirements for formed concrete surfaces shall be as specified in ACI 301.

B. Rough-Formed Finish: As-cast concrete texture imparted by form-facing material with tie holes and defects repaired and patched. Remove fins and other projections that exceed specified limits on formed-surface irregularities.
   1. Apply to concrete surfaces not exposed to public view.

C. Smooth-Formed Finish: As-cast concrete texture imparted by form-facing material, arranged in an orderly and symmetrical manner with a minimum of seams. Repair and patch tie holes and defects. Remove fins and other projections that exceed specified limits on formed-surface irregularities.
   1. Apply to concrete surfaces exposed to public view, to receive a rubbed finish, or to be covered with a coating or covering material applied directly to concrete.

D. Related Unformed Surfaces: At tops of walls, horizontal offsets, and similar unformed surfaces adjacent to formed surfaces, strike off smooth and finish with a texture matching adjacent formed surfaces. Continue final surface treatment of formed surfaces uniformly across adjacent unformed surfaces unless otherwise indicated.

3.14 FINISHING FLOORS AND SLABS

A. General: Comply with ACI 302.1R recommendations for screeding, restraightening, and finishing operations for concrete surfaces. Do not wet concrete surfaces.

B. Edge all slabs, pads, driveways, and ramps and finish with a light broom finish. The tops of foundations shall receive a steel trowel finish. Interior slabs in pump houses shall have a smooth finish to aid cleanup of minor spills.

C. The finish on all sidewalks shall be obtained with a light broom finish after edging. Broom direction shall be perpendicular to the direction of traffic.

D. Scratch Finish: While concrete is still plastic, texture concrete surface that has been screeded and bull-floated or darbied. Use stiff brushes, brooms, or rakes to produce a profile amplitude of 1/4 inch in one direction.

1. Apply scratch finish to surfaces indicated and to receive concrete floor toppings, to receive mortar setting beds for bonded cementitious floor finishes.

E. Float Finish: Consolidate surface with power-driven floats or by hand floating if area is small or inaccessible to power-driven floats. Restraighten, cut down high spots, and fill low spots. Repeat float passes and restraightening until surface is left with a uniform, smooth, granular texture.
   1. Apply float finish to surfaces indicated to receive trowel finish and to be covered with fluid-applied or sheet waterproofing, built-up or membrane roofing.

F. Trowel Finish: After applying float finish, apply first troweling and consolidate concrete by hand or power-driven trowel. Continue troweling passes and restraighten until surface is free of trowel marks and uniform in texture and appearance. Grind smooth any surface defects that would telegraph through applied coatings or floor coverings.
   1. Apply a trowel finish to surfaces indicated exposed to view or to be covered with resilient flooring, carpet, ceramic or quarry tile set over a cleavage membrane, paint, or another thin-film-finish coating system.
   2. Finish surfaces to the following tolerances, according to ASTM E1155, for a randomly trafficked floor surface:
      a. Do not steel trowel mixes with entrained air required for freeze-thaw durability.
      b. Finish and measure surface, so gap at any point between concrete surface and an unleveled, freestanding, 10-ft.-long straightedge resting on two high spots and placed anywhere on the surface does not exceed 1/8 inch. Compliance with the designated tolerance in four of five consecutive measurements shall be considered satisfactory unless obvious faults are observed.

G. Trowel and Fine-Broom Finish: Apply a first trowel finish to surfaces indicated where ceramic or quarry tile is to be installed by either thickset or thinset method. While concrete is still plastic, slightly scarify surface with a fine broom.
   1. Comply with flatness and levelness tolerances for trowel-finished floor surfaces.

H. Broom Finish: Apply a broom finish to exterior concrete platforms, steps, ramps, and elsewhere as indicated.
   1. Immediately after float finishing, slightly roughen trafficked surface by brooming with fiber-bristle broom perpendicular to main traffic route. Coordinate required final finish with Designer before application.

I. Slip-Resistive Finish: Before final floating, apply slip-resistive aluminum granule finish where indicated and to concrete stair treads, platforms, and ramps. Apply according to manufacturer's written instructions and as follows:
   1. Uniformly spread 25 lb./100 sq. ft. (of dampened slip-resistive aluminum granules over surface in one or two applications. Tamp aggregate flush with surface, but do not force below surface.
   2. After broadcasting and tamping, apply float finish.
   3. After curing, lightly work surface with a steel wire brush or an abrasive stone and water to expose slip-resistive aluminum granules.

J. Protect the floor from paint, plaster, drippings, dirt, oils, and marring by heavy objects or construction traffic.

3.15 MISCELLANEOUS CONCRETE ITEM INSTALLATION

A. Filling In: Fill in holes and openings left in concrete structures after work of other trades is in place unless otherwise indicated. Mix, place, and cure concrete, as specified, to blend with in-place construction. Provide other miscellaneous concrete filling indicated or required to complete the work.

B. Curbs: Provide monolithic finish to interior curbs by stripping forms while concrete is still green and by steel-troweling surfaces to a hard, dense finish with corners, intersections, and terminations slightly rounded.

C. Equipment Bases and Foundations:
   1. Coordinate sizes and locations of concrete bases with actual equipment provided.
   2. Construct concrete bases 8 inches high unless otherwise indicated, and extend base not less than 6 inches in each direction beyond the maximum dimensions of supported equipment unless otherwise indicated or unless required for seismic anchor support.
   3. Minimum Compressive Strength: 5000 psi at 28 days.
   4. Install dowel rods to connect concrete base to concrete floor. Unless otherwise indicated, install dowel rods on 18 inch centers around the full perimeter of concrete base.
   5. For supported equipment, install hot-dipped galvanized anchor bolts that extend through concrete base and anchor into structural concrete substrate.
   6. Prior to pouring concrete, place and secure anchorage devices. Use setting drawings, templates, diagrams, instructions, and directions furnished with items to be embedded.
   7. Cast anchor-bolt insert into bases. Install anchor bolts to elevations required for proper attachment to supported equipment.

D. Steel Pan Stairs: Provide concrete fill for steel pan stair treads, landings, and associated items. Cast-in inserts and accessories as shown on Agreement Drawings. Screed, tamp, and trowel finish concrete surfaces.

3.16 CONCRETE PROTECTING AND CURING

A. General: Protect freshly placed concrete from premature drying and excessive cold or hot temperatures. Comply with ACI 306R and ACI 306.1 for cold-weather protection and ACI 305R and ACI 305.1 for hot-weather protection during curing.

B. Evaporation Retarder: Apply evaporation retarder to unformed concrete surfaces if hot, dry, or windy conditions cause moisture loss approaching 0.2 lb/sq. ft. x h before and during finishing operations. Apply according to manufacturer's written instructions after placing, screeding, and bull floating or darbying concrete, but before float finishing.

C. Formed Surfaces: Cure formed concrete surfaces, including underside of beams, supported slabs, and other similar surfaces. If forms remain during curing period, moist cure after loosening forms. If removing forms before end of curing period, continue curing for remainder of curing period.

D. Unformed Surfaces: Begin curing immediately after finishing concrete. Cure unformed surfaces, including floors and slabs, concrete floor toppings, and other surfaces.

E. Cure concrete according to ACI 308.1, by one or a combination of the following methods:

1. Moisture Curing: Keep surfaces continuously moist for not less than seven days with the following materials:
   a. Water.
   b. Continuous water-fog spray.
   c. Absorptive cover, water saturated, and kept continuously wet. Cover concrete surfaces and edges with 12 inch lap over adjacent absorptive covers.
2. Moisture-Retaining-Cover Curing: Cover concrete surfaces with moisture-retaining cover for curing concrete, placed in widest practicable width, with sides and ends lapped at least 12 inches, and sealed by waterproof tape or adhesive. Cure for not less than seven days. Immediately repair any holes or tears during curing period, using cover material and waterproof tape.
   a. Moisture cure or use moisture-retaining covers to cure concrete surfaces to receive floor coverings.
   b. Cure concrete surfaces to receive floor coverings with either a moisture-retaining cover or a curing compound that the manufacturer certifies does not interfere with bonding of floor covering used on project.
3. Curing Compound: Apply uniformly in continuous operation by power spray or roller according to manufacturer's written instructions. Recoat areas subjected to heavy rainfall within three hours after initial application. Maintain continuity of coating and repair damage during curing period.
   a. Removal: After curing period has elapsed, remove curing compound without damaging concrete surfaces by method recommended by curing compound manufacturer unless manufacturer certifies curing compound does not interfere with bonding of floor covering used on project.
4. Curing and Sealing Compound: Apply uniformly to floors and slabs indicated in a continuous operation by power spray or roller according to manufacturer's written instructions. Recoat areas subjected to heavy rainfall within three hours after initial application. Repeat process 24 hours later and apply a second coat. Maintain continuity of coating and repair damage during curing period.

3.17 JOINT FILLING

A. Prepare, clean, and install joint filler according to manufacturer's written instructions.
   1. Defer joint filling until concrete has aged at least one month. Do not fill joints until construction traffic has permanently ceased.

B. Remove dirt, debris, saw cuttings, curing compounds, and sealers from joints; leave contact faces of joints clean and dry.

C. Install semirigid joint filler full depth in saw-cut joints and at least 2 inches deep in formed joints. Overfill joint and trim joint filler flush with top of joint after hardening.

3.18 CONCRETE SURFACE REPAIRS

A. Defective Concrete: Repair and patch defective areas when approved by Company. Remove and replace concrete that cannot be repaired and patched.

B. Repair of voids, honeycomb, sand pockets, excessive finings, and similar imperfections shall be completed as soon as practical after removal of forms. Curing procedures shall not be delayed or interrupted while such repairs are made.

C. Repairs shall conform to the requirements of ACI 546R and repair materials to ACI 546.3R.

D. Use only prequalified repair materials and procedures.

E. Repairing Formed Surfaces: Surface defects include color and texture irregularities, cracks, spalls, air bubbles, honeycombs, rock pockets, fins and other projections on the surface, and stains and other discolorations that cannot be removed by cleaning.
   1. Immediately after form removal, cut out honeycombs, rock pockets, and voids more than 1/2 inch in any dimension or 1/4 inch in depth to solid concrete. Limit cut depth to 3/4 inch. Make edges of cuts perpendicular to concrete surface. Clean, dampen with water, and brush-coat holes and voids with bonding agent. Fill and compact with patching mortar before bonding agent has dried. Fill form-tie voids with patching mortar or cone plugs secured in place with bonding agent.
   2. Repair defects on concealed formed surfaces that affect concrete's durability and structural performance as determined by Designer.

F. Repairing Unformed Surfaces: Test unformed surfaces, such as floors and slabs, for finish and verify surface tolerances specified for each surface. Correct low and high areas. Test surfaces sloped to drain for trueness of slope and smoothness; use a sloped template.
   1. Repair finished surfaces containing defects. Surface defects include spalls, popouts, honeycombs, rock pockets, crazing and cracks in excess of 0.01 inch wide or that penetrate to reinforcement or completely through unreinforced sections regardless of width, and other objectionable conditions.
   2. After concrete has cured at least 14 days, correct high areas by grinding.
   3. Correct localized low areas during or immediately after completing surface finishing operations by cutting out low areas and replacing with patching mortar. Finish repaired areas to blend into adjacent concrete.
   4. Correct other low areas scheduled to receive floor coverings with a repair underlayment. Prepare, mix, and apply repair underlayment and primer according to manufacturer's written instructions to produce a smooth, uniform, plane, and level surface. Feather edges to match adjacent floor elevations.
   5. Correct other low areas scheduled to remain exposed with a repair topping. Cut out low areas to ensure a minimum repair topping depth of 1/4 inch to match adjacent floor elevations. Prepare, mix, and apply repair topping and primer according to manufacturer's written instructions to produce a smooth, uniform, plane, and level surface.
   6. Repair defective areas, except random cracks and single holes 1 inch or less in diameter, by cutting out and replacing with fresh concrete. Remove defective areas with clean, square cuts and expose steel reinforcement with at least a 3/4 inch clearance all around. Dampen concrete surfaces in contact with patching concrete and apply bonding agent. Mix patching concrete of same materials and mixture as original concrete, except without coarse aggregate. Place, compact, and finish to blend with adjacent finished concrete. Cure in same manner as adjacent concrete.
   7. Repair random cracks and single holes 1 inch or less in diameter with patching mortar. Groove top of cracks and cut out holes to sound concrete and clean off dust, dirt, and loose particles. Dampen cleaned concrete surfaces and apply bonding agent. Place patching mortar before bonding agent has dried. Compact patching mortar and finish to match adjacent concrete. Keep patched area continuously moist for at least 72 hours.

G. Perform structural repairs of concrete, subject to Company's approval, using epoxy adhesive and patching mortar.

H. Repair materials and installation not specified above may be used, subject to Company's approval.

3.19 CLEANUP AND DISPOSAL

A. All construction shall be in conformance with Company environmental guidelines for construction. Upon satisfactory completion of the work, remove all tools, equipment, surplus material, and debris resulting from the concreting operation. All wastes generated during concrete construction (including domestic wastes) shall be removed from the site and disposed of at an approved facility. The disposal of all waste materials is the responsibility of the Contractor. Manage all wastes in accordance with the waste management plan.

3.20 FIELD QUALITY CONTROL

A. Concrete Materials Only: In accordance with Section 033100 "Structural Concrete Materials".

B. At a minimum, include the following items in the Inspection and Test Plan:
   1. Surveillance:
      a. Formwork cleanliness after preparation.
      b. Proper application of release agent.
      c. Concrete placement and consolidation.
      d. Concrete surface finishing.
      e. Curing and protection procedures.
      f. Testing and inspection.
   2. Review:
      a. Concrete test results.
   3. Verification:
      a. Plastic and hardened concrete test results.
   4. Witness Point:
      a. Concrete finishing inspection.
   5. Hold Point:
      a. Hot weather and cold weather concrete plan.
      b. Reinforcement placement shop drawings approved.
      c. Sub-base preparation.
      d. Reinforcing steel and embedments properly placed and secured in formwork.
      e. Repair procedures.
      f. Repair inspection.
      g. Removal of formwork and falsework.
      h. Reuse of forms.

C. Periodic Special Inspections:
   1. Steel reinforcement placement.
   2. Formwork shape and dimension.
   3. Verify weldability of steel reinforcement other than ASTM A706.
   4. Inspect single-pass fillet welds of maximum 5/16 inch leg length.
   5. Anchors cast in concrete.

6. Post-installed mechanical anchors.
7. Verification of use of required design mixture.
8. Concrete placement, including conveying and depositing.
9. Curing procedures and maintenance of curing temperature.
10. Verification of concrete strength before removal of shores and forms from beams and slabs.

D. Continuous Special Inspections:
1. Steel reinforcement welding not covered in scope of Periodic Special Inspections.
2. Post-installed adhesive anchors.

E. Concrete Tests: In accordance with Section 033100 “Structural Concrete Materials”.

F. Measure floor and slab flatness and levelness according to ASTM E1155 within 48 hours of finishing.

G. Provide a minimum of 24 hours’ notice prior to the start of concrete placement to allow the Company time to inspect the formwork and reinforcement. Do not place concrete until the Company has approved inspection of foundations, forms, reinforcing steel, embedded parts and methods of curing and protecting concrete.

H. Concrete production and placement shall not take place until the Company is satisfied that all equipment and other surfaces within proximity of placement activities are protected from splashes and spills. Tarps, polyethylene sheets, or other similar materials may be used if they do not pose a fire hazard. Maintain adequate access and operability requirements, provide adequate ventilation, and satisfy construction safety requirements, all to the satisfaction of the Company.

END OF SECTION 033000

SECTION 033100 – STRUCTURAL CONCRETE MATERIALS

PART 1 - GENERAL

1.1 SUMMARY

A. Section Includes:
   1. Materials used in the design and development of concrete mixes, batching and mixing of materials.
   2. Quality control (QC) required for structural concrete materials.
   3. Works related to furnishing, transporting, placement, compaction and curing concrete mixes for the cast-in-place and precast concrete elements of the project, except for the precast concrete tunnel lining (PCTL). Refer to Section 317416 “Precast Concrete Tunnel Lining” for concrete mixes to be developed for the PCTL.

B. Related Requirements:
   1. Section 033000 “Cast in Place Concrete”.

1.2 DEFINITIONS

A. Cementitious Materials: Portland cement alone or in combination with one or more of the following: blended hydraulic cement, fly ash, slag cement, other pozzolans, and silica fume; materials subject to compliance with requirements.

B. Fly Ash (FA): (Type F), (ASTM C618).

C. Ground Granulated Blast Furnace Slag (GGBFS): Supplementary cementitious material produced from slag byproduct of iron production using blast furnaces, also known as slag cement, grade 100 or grade 120 (ASTM C989).

D. Lightweight Aggregate Concrete (LWAC): Concrete containing lightweight aggregates with an oven dry density of 125 lbs/ft3 or less.

E. Silica Fume (SF): (ASTM C1240).

F. W/C Ratio: The ratio by weight of water to cementitious materials.

1.3 REFERENCES

A. National Ready Mixed Concrete Association (NRMCA):
   1. Quality Management System for Ready Mixed Concrete Companies.
   2. Quality Certification Program Certification Criteria Document.
   3. Plant Certification Checklist.
   4. Delivery Fleet Inspection Form.

B. ASTM International (ASTM):

1. ASTM C31 Standard Practice for Making and Curing Concrete Test Specimens in the Field.
2. ASTM C33 Standard Specification for Concrete Aggregates.
3. ASTM C39 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.
4. ASTM C40 Standard Test Method for Organic Impurities in Fine Aggregates for Concrete.
5. ASTM C42 Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete.
6. ASTM C94 Standard Specification for Ready-Mixed Concrete.
7. ASTM C143 Standard Test Method for Slump of Hydraulic-Cement Concrete.
8. ASTM C150 Standard Specification for Portland Cement.
9. ASTM C172 Standard Practice for Sampling Freshly Mixed Concrete.
10. ASTM C231 Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method.
11. ASTM C260 Standard Specification for Air-entraining Admixtures for Concrete.
12. ASTM C457 Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete.
13. ASTM C494 Standard Specification for Chemical Admixtures for Concrete.
14. ASTM C595 Standard Specification for Blended Hydraulic Cements.
15. ASTM C618 Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.
16. ASTM C666 Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing.
17. ASTM C856 Standard Practice for Petrographic Examination of Hardened Concrete.
18. ASTM C989 Standard Specification for Slag Cement for Use in Concrete and Mortars.
19. ASTM C1064 Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete.
20. ASTM C1077 Standard Practice for Agencies Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Testing Agency Evaluation.
21. ASTM C1152 Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete.
22. ASTM C1202 Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration.
23. ASTM C1240 Standard Specification for Silica Fume Used in Cementitious Mixtures.
24. ASTM C1260 Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method).
25. ASTM C1567 Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method).
26. ASTM C1602 Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete.
27. ASTM C1778 Standard Guide for Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete.

C. American Concrete Institute (ACI):
1. ACI 117 Specification for Tolerances for Concrete Construction and Materials and Commentary.
2. ACI 211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete.
3. ACI 301 Specifications for Structural Concrete.
4. ACI 304R Guide for Measuring, Mixing, Transporting, and Placing Concrete.

5. ACI 304.2R Guide to Placing Concrete by Pumping Methods.
6. ACI 207.1R Guide to Mass Concrete.
7. ACI 305.1 Specification for Hot Weather Concreting.
8. ACI 305R Guide to Hot Weather Concreting.
9. ACI 306.1 Specification for Cold Weather Concreting.
10. ACI 306R Guide to Cold Weather Concreting.
11. ACI 309R Guide for Consolidation of Concrete.
12. ACI 318 Building Code Requirements for Structural Concrete.

D. Nord Test:
1. NT BUILD 492 Concrete, mortar and cement-based repair materials: Chloride migration coefficient from non-steady-state migration experiments.

E. Euronorm:
1. EN 206 Concrete — Specification, performance, production and conformity.

F. American Association of State Highway and Transportation Officials (AASHTO):
1. AASHTO T21 Standard Method of Test for Organic Impurities in Fine Aggregates for Concrete.
2. AASHTO T71 The effect of organic impurities in fine aggregates on strength of mortar.
3. AASHTO R81 Standard Practice for Static Segregation of Hardened Self-Consolidating Concrete (SCC) Cylinders.

G. Fib International:
1. Fib-34 Model Code for Service Life Design.

1.4 PRECONSTRUCTION MEETINGS

A. Prequalification Conferences: Conduct conferences at project site.

B. Include relevant items from this Section in agenda for concrete mix development preconstruction meeting.
1. Before submitting design mixtures, review concrete design mixture and examine procedures for ensuring quality of concrete materials. Require representatives of each entity directly concerned with cast-in-place concrete to attend, including the following:
   a. Contractor's superintendent.
   b. Independent Testing Agency responsible for concrete design mixtures.
   c. Ready-mix concrete manufacturer.
   d. Concrete Subcontractor, if applicable.
2. Review special inspection and testing and inspection procedures for field QC, cold- and hot-weather concreting procedures affecting mix design and adjustments to batching and mixing.

1.5 ACTION SUBMITTALS

A. Product Data: Supply product data for the following:
1. Prequalification mix development repot for each ready-mixed concrete mix design. Reference ACI 211.1.
2. Cement, fly ash, GGBFS and silica fume.

3. Admixtures (such as air-entraining and water-reducing admixtures).
4. Aggregates.

1.6 INFORMATIONAL SUBMITTALS

A. Qualification Data: Submit evidence that the key personnel and equipment operators to be used for this project have experience in concrete mix development and batching mixes similar to those specified for this project. To be submitted at least two weeks prior to the start of installation. Include all Testing Agencies and testing personnel.

B. Material certificates for each of the following, signed by manufacturers:
1. Cementitious materials.
2. Admixtures.
3. Aggregates: Grading, durability and service record data indicating absence of deleterious expansion of concrete due to alkali aggregate reactivity dated less than 1 year from start of project.

C. Minutes of preconstruction meeting, including closure or all action items.

1.7 QUALITY ASSURANCE

A. Qualifications:
1. Ready-mix Concrete Manufacturer:
   a. A firm experienced in manufacturing ready-mixed concrete products and that complies with ASTM C94 requirements for production facilities and equipment.
   b. Certified according to NRMCA's "Certification of Ready Mixed Concrete Production Facilities." and shall have an equivalent quality management system documented in a quality manual.
   c. Capacity, production rate, and delivery rate of the plant sufficient to complete the work without forming cold joints in the concrete.
   d. Capability to produce and deliver concrete, meeting the requirements of the Agreement Drawings and Specifications.
   e. Contingency plan for a back-up plant in the event of a mechanical malfunction of one of the primary plant(s).
   f. Alternative sources of key cementitious materials in the event of the primary source being unable to supplied certified material. If multiple sources for each cementitious material are used all sources must be prequalified during mix development.
   g. Key personnel and equipment operators to be used for this project shall have experience in concrete mix development and batching mixes similar to those specified for this project.

1.8 PRECONSTRUCTION TESTING

A. Prequalify all the mixes to be used on this project by preparing design mixtures and preparing and submitting a prequalification mix development report.

B. Design Mixtures: Prepare design mixtures for each type and strength of concrete, proportioned on the basis of laboratory trial mixture or field test data, or both, according to ACI 301. Submit alternate design mixtures when characteristics of materials, project conditions, weather, test results, or other circumstances warrant adjustments. Use ACI 211.1 as a guide for determining mix proportions for concrete, except for concrete to be pumped. For pumped concrete, use the mix proportions recommended in ACI 304.2R.
   1. Use a qualified independent Testing Agency for preparing and reporting proposed mixture designs based on laboratory trial mixtures.
   2. Perform all tests using a testing laboratory certified in accordance with the requirements of ASTM C1077.
   3. Sample and test in accordance with ACI 304R.

C. Cementitious Materials: Limit percentage, by mass, of cementitious materials other than portland cement in concrete in accordance with Table 4.

D. Limit water-soluble, chloride-ion content in hardened concrete to 0.06 percent by weight of cement.

E. Limit acid-soluble, chloride-ion content in hardened concrete exposed to de-icing salts or chlorides ions from other sources to 0.10 percent by weight of cement: ASTM C1152.

F. Admixtures: Use admixtures according to manufacturer's written instructions.
   1. Use water-reducing, high-range water-reducing or plasticizing admixture in concrete, as required, for placement and workability.
   2. Use water-reducing, -retarding or -hydration stabilizing admixtures when required by high temperatures, low humidity, or other adverse placement conditions.
   3. Use water-reducing admixture in pumped concrete, concrete for heavy-use industrial slabs and parking structure slabs, concrete required to be watertight, and concrete with a w/c ratio below 0.50.
   4. Use corrosion-inhibiting admixture in concrete mixtures where indicated.

G. Prequalification Mix Development Report: Provide report covering development of concrete mixes and final selection. Submit at least four weeks prior to the start of installation. Report shall cover the following as a minimum:
   1. The nature and source of each constituent material.
   2. Cement mill test report and test results.
   3. Fly ash test results as specified by ASTM C618.
   4. GGBFS tests results as specified in ASTM C989.
   5. Silica fume test results as specified in ASTM C1240.
   6. Aggregate test results as specified by ASTM C33.
   7. Water test results as specified by ASTM C1602.
   8. The source of supply of concrete and any proposed alternative sources.
   9. The mix designs for the different aspects of construction giving proposed mix proportions and quantities of each constituent material per cubic yard of compacted concrete.
   10. Details of admixtures to be used.
   11. Evidence of suitability of proposed mix proportions to meet the requirements of this Section, based on prequalification testing.
   12. Certification of quality assurance.
   13. Information on aggregates required by this Section.
   14. Workability and workability retention of concrete mix.
   15. Confirmation of the strength and density properties of the concrete.

16. Evidence the ready-mix plant(s), equipment, and all materials to be used in the concrete comply with the requirements of ASTM C94.
17. All other information regarding constituent materials, including QA such as test certificates, required by this Section.
18. Provide the following test results performed by a certified laboratory for each mix type in the prequalification mix development report:
    a. Concrete compressive strength at 3, 7, 28 and 56 days.
    b. Splitting tensile strength at 28 days.
    c. Water soluble and acid-soluble chloride ion content of mix to ASTM C1152.
    d. Chloride ion penetrability to ASTM C1202.
    e. Rapid chloride migration test to NT Build 492.
    f. Alkali-aggregate reaction resistance to ASTM C1260/1567 or as required by ASTM C1778.
    g. Coefficient of thermal expansion.
    h. Shrinkage at 7, 21, 28 and 56 days.
    i. Heat of hydration.
    j. Entrained air-void system: ASTM C457, ASTM C856.
    k. Freeze-thaw resistance: ASTM C666.
    l. Fresh concrete temperature and control of heat of hydration.
    m. Workability.
    n. Setting time.

H. If existing mix designs are proposed to be used provide the test results listed in Section 1.8A based on documentation less than 1 year old at start of project.

1.9 DELIVERY, STORAGE, AND HANDLING

A. All material storage shall comply with ASTM C94.

B. The ready-mixed concrete truck driver shall provide the batch ticket at the time of concrete delivery. The ticket shall summarize the following information legibly in an easily discernible table:
1. Weight in pounds of all materials, except the water reducing and air-entraining agents which shall be in ounces.
2. Cubic yards batched.
3. The ratio of water to cementitious (W/C) materials ratio.
4. Temperature of the concrete at the time it was batched.
5. Time of batching.
6. Free moisture in the fine and coarse aggregates in percent of weight of aggregate.
7. Concrete mix design number.
8. Amount of additional water (if any) added at the plant and at the site.

1.10 FIELD CONDITIONS

A. Not used.

PART 2 - PRODUCTS

2.1 CONCRETE, GENERAL

A. ACI Publications: Comply with the following unless modified by requirements in the Agreement Drawings or this Section:
   1. ACI 301.
   2. ACI 117.

B. Source Limitations: Obtain each type or class of cementitious material of the same brand from the same manufacturer's plant, obtain aggregate from single source, and obtain admixtures from single source from single manufacturer.

C. Cementitious Materials:
   1. Portland Cement: ASTM C150, Type I, Type II, Type I/II, Type IV, Type V.
   2. Fly Ash: ASTM C618, Class F.
   3. Slag Cement: ASTM C989, Grade 100.
   4. Silica Fume: ASTM C1240, amorphous silica.
   5. Blended Hydraulic Cement: ASTM C595, Type IS (Portland-slag cement), Type IP (Portland-pozzolan cement), Type IT (Ternary blended cement).
   6. Minimum and maximum cement replacements levels to be in accordance with Table 4.

D. Normal-Weight Aggregates:
   1. Coarse Aggregates:
      a. ASTM C33, Class 3S class coarse aggregate or better, graded. Provide aggregates from a single source with documented service record data of at least 10 years' satisfactory service in similar applications and service conditions using similar aggregates and cementitious materials.
      b. Provide coarse aggregate for concrete that meet the grading requirements of Table 1 and the physical requirements of Table 2.

Table 1: Grading Requirements for Coarse Aggregates

Series/ Class	**Sieve Analysis (MTM 109) Total Percent Passing [a]**							**Loss by Washing (MTM 108) % Passing**
	1 ½ in	1 in	¾ in	½ in	3/8 in	No.4	No.8	No. 200 [a]
6AA	100	90-100	-	30-60	-			≤1.0 [b]
17A	-	100	90-100	50-75	-	0-8	-	≤1.0 [b]
26A	-	-	100	95-100	60-90	5-30	0-12	≤1.0 [b]

[a] Based on dry weights.
[b] Loss by washing will not exceed 2.0 percent for material produced entirely by crushing rock, boulders, cobbles, slag, or concrete.

Table 2: Physical Requirements for Coarse Aggregates

Properties	Test Standard	Physical Requirements for Coarse Aggregates (Gravel or Stone)	Notes
Crushed material, % min	MTM 117	-	
Loss, % max, Los Angeles Abrasion	MTM 102	40	
Soft particles, % max	MTM 110	2.0	
Sum of soft Particles and Chert, % max	MTM 110	4.0	
Freeze-Thaw dilation, % per 100 cycle max	MTM 115	0.010	(a)
Total acid soluble sulfates %, max	EN 1744	0.2	
Iron pyrite and pyrrhotite %, max	EN 1744	0.1	(b)

(a) If the relative density OD is more than 0.04 less than the relative density OD of the most recently tested freeze-thaw sample, the aggregate will be considered to have changed characteristics and be required to have a new freeze-thaw test conducted prior to use.
(b) If petrography detects the presence of iron pyrites or pyrrhotites a maximum total sulfur content of 0.1 % apply.

c. Maximum coarse aggregate size: refer to Table 5 for nominal size.
d. The maximum aggregate size shall meet the requirements of ACI 301.

2. Fine aggregate for concrete. Furnish conforming to the following sections:
   a. Natural sand, 2NS which is the result from the natural disintegration of rock.
   b. Manufactured sand, 2MS produced by totally crushing rock or gravel.
   c. Stone sand, SS which is manufactured from stone meeting all the physical requirements of Table 2. Stone sand is permitted only in structural concrete not exposed to vehicular traffic.
   d. The material must be clean, hard, durable, uncoated particles of sand, free from clay lumps and soft or flaky material.
   e. Grading: Uniformly grade the aggregate from coarse to fine in accordance with Table 3.

Table 3: Grading Requirements for Fine Aggregates

Series/ Class	Sieve Analysis (MTM 109) Total Percent Passing (a)							Loss by Washing (MTM 108) % Passing
	3/8 in	No.4	No.8	No.16	No.30	No.50	No.100	No. 200 (a), (b)
2NS(c)	100	95-100	65-95	35-75	20-55	10-30	0-10	0-3.0
2SS (d)	100	95-100	65-95	35-75	20-55	10-30	0-10	0-4.0
2MS(c)	-	100	95-100	-	-	15-40	0-10	0-3.0

(a) Test results based on dry weights.
(b) Use test method MTM 108 for Loss by Washing Loss.
(c) Max. allowed fineness modulus variation of ± 0.20. Aggregate having a fineness modulus differing from the base fineness modulus of the source by the amount exceeding the maximum variation of ± 0.20, will be rejected. Use ASTM C136. The base fineness modulus will be supplied by the aggregate producer at the start of each construction season and be within the range of 2.50 to 3.35. The base FM, including the permissible variation, will be within the 2.50 to 3.35 range.
(d) Quarried carbonate (limestone or dolomite) cannot be used for any application subject to vehicular traffic.

f. Test for organic impurities in accordance with AASHTO T21: The aggregate must not produce a color darker than organic plate no. 3 (gardener color standard no.11). Designer may approve the use of fine aggregate that fails the test for organic impurities based on one of the following:
   1) The discoloration resulted from small quantities of coal, lignite, or similar discrete particles, or
   2) The tested concrete develops a relative seven-day strength of at least 95 percent in accordance with AASHTO T71.

g. Fine aggregate 2NS, 2SS, and 2MS must meet fineness modulus requirements in Table 3.
h. Do not use crushed portland cement concrete fine aggregate in concrete mixtures.

3. Alkali-silica reactivity. The potential for deleterious alkali-aggregate reactivity for fine and coarse aggregates shall be assessed in accordance with ASTM C1778 for structural class S4 for aggregates with a maximum aggregate reactivity class of R2. Adopt one of the following approaches to reduce the risk of deleterious alkali-aggregate reactivity:
   a. Prescriptive approach in accordance with ASTM C1778 and submit alkali-silica reactivity with cementitious material to ASTM C1567, performed on the approved mix design. Do not use lithium compounds as mitigation measures. A limiting expansion of ≤ 0.10 percent at 16 days after casting applies.
   b. Performance approach in accordance with ASTM C1778.

E. Water: ASTM C94, ASTM C1602 and potable.

F. Chemical Admixtures: Certified by manufacturer to be compatible with other admixtures and that do not contribute water-soluble chloride ions exceeding those permitted in hardened concrete. Do not use calcium chloride or admixtures containing calcium chloride.
1. Water-Reducing Admixture: ASTM C494, Type A.
2. Retarding Admixture: ASTM C494, Type B.
3. Water-Reducing and Retarding Admixture: ASTM C494, Type D.
4. High-Range, Water-Reducing Admixture: ASTM C494, Type F.
5. High-Range, Water-Reducing and Retarding Admixture: ASTM C494, Type G.
6. Air Entraining Agents: ASTM C260.
7. Unless otherwise shown on the Agreement Drawings, the amount of air-entraining agent used in each concrete mix shall be such as will affect the entrainment of the percentage of air shown in Table 5 in the concrete as discharged from the mixer or pumper discharge hose if applicable.
8. The level of exposure shall be as shown in Table 5.
9. When a batch of concrete delivered to the project does not conform to the minimum specified air content, an air-entraining admixture may be added, 1 time only for the batch prior to consideration for rejection. After the admixture is added, the concrete shall be remixed for a minimum of 20 revolutions of the mixer drum at mixing speed. The concrete shall then be retested and if found acceptable, may be placed in accordance with this Section.

G. Set-Accelerating Corrosion-Inhibiting Admixture: Commercially formulated, anodic inhibitor or mixed cathodic and anodic inhibitor; capable of forming a protective barrier and minimizing chloride reactions with steel reinforcement in concrete and complying with ASTM C494, type C.

H. Non-Set-Accelerating Corrosion-Inhibiting Admixture: Commercially formulated, non-set-accelerating, anodic inhibitor or mixed cathodic and anodic inhibitor; capable of forming a protective barrier and minimizing chloride reactions with steel reinforcement in concrete.

2.2 CONCRETE MIXES

A. The concrete mixes required for the works are summarized in Table 5.

B. Blended hydraulic cement types or equivalent combinations with supplementary cementing materials levels shall be in accordance with Table 4.

Table 4: Permitted Cement Types and Equivalent Combinations

Type	Designation of Blended Cement to ASTM C595	Combination Type I/II/IV/V + SCM [a]	Type Description	Composition (percentage by mass of total cementitious material)		
				Percentage of Supplementary Cementitious Materials in Blended Cements or Concretes		
				Fly-Ash	Blast-Furnace Slag	Silica Fume
				F	S	SF
A	Type IP	I/II + fa	Portland-fly ash	15 - 35	-	-
B	IT(S)(P) [b]	I/II + slag + fa	Ternary blended cement	15 - 25	25-35	-
C	IT(P)(SF) [c]	I/II + fa + sf	Ternary blended cement	15 - 30	-	5 - 8
D	IT(S)(SF) [d]	I/II + slag + sf	Ternary blended cement		20 - 45	5 - 10
E	Type S	I/II + slag	Blast-furnace cement	-	70 - 80	-
F	Type IS	I/II + slag	Blast-furnace	-	36 - 50	-
G	Type IP	I/II + sf	Portland-silica fume	-	-	10 - 11

[a] When used in combination with SCMs, Type I/II cements are preferred. They may be replaced with Type IV or Type V where required.
[b] Total cement replacement not to exceed 60%.
[c] Total cement replacement not to exceed 35%.
[d] Total cement replacement not to exceed 45%.

C. Resistance to chloride ingress ($D_{RCM,0}$, RCPT) and/or carbonation ($R_{ACC,0}$) shall be determined during initial trials and meet the performance requirements of Table 5.

Table 5: Concrete Mixes and Properties

Application/ Properties		Standard / Spec. Ref.	Unit	Precast Tunnel Roadway	Precast Access Tunnel	Permanent Below-grade Portal Structures (includes ALL diaphragm walls, both permanent and temporary)	Temporary Below-grade Structures (not including diaphragm walls)	Slabs on Metal Deck, Interior Above Grade Elements	Exterior Above Grade Elements, Shallow Foundations	Below-Grade Miscellaneous (duct banks)
Design service life			years	99	99	99	5	99	99	99
Concrete class				Class A (AE)	Class A (AE)	Class A (AE)	Class B (AE)	Class B (AE)	Class A (AE)	Class C (AE)
Compressive strength, 28-day [b]		-	psi	5000	6000	6000	5000	5000	4500	4000
Project exposure class [c]		-	-	XC3+F1	S0+XD1+XC4+F2	S0+F2	S0+XD1+XC4+F2	F0	S0+XD3+F3	S0+F2
Nominal aggregate size, max		-	inches	¾"	¾"	1"	1"	¾"	1"	0.5"
Cement types or combinations [d]		Table	-	A, B, C, D, F, G	A, B, C, D, F, G	A, B, C, D, E, F	A, B, C, D, E, F	A, B, C, D, E, F	A, B, C, D, F	A, B, C, D, F
Cement + additions, min / max		-	lbs/cy	611/ 800	611/ 800	564 / 800	-	517 / 800	658 / 800	658 / 800
Max. water/(c+a) ratio [e]		-	-	0.42	0.42	0.49	0.58	0.50	0.45	0.45
Water-soluble chloride		ASTM C1218	%/cem.	≤0.15	≤0.15	≤0.15	≤0.15	≤0.15	≤0.06	≤0.15
Acid-soluble chloride		ASTM C1552	%/cem.	-	-	-	-	-	≤0.10	-
Temp. fresh concrete min/max		ASTM C1064	°F	40 / 95	40 / 95	40 / 85	40 / 85	40 / 85	40 / 85	40 / 85
Air content		ASTM C231	%	6 ± 1.5	6 ± 1.5	6 ± 1.5	5 ± 1.5	5 ± 1.5	7 ± 1.5	7 ± 1.5
Air void spacing factor		ASTM C457	µm	[f]	[f]	[f]	[f]	-	[f]	[f]
Durability factor		ASTM C666	%	[g]	[g]	[g]	[g]	-	[g]	[g]
Water permeability		CRD-C 48		-	-	-	-	-	-	-
RCPT [i]		ASTM C1202	Coulomb	-	≤1500	≤1500	-	-	≤700	-
$D_{RCM,0}$ (mean/max) [j]	A: I/II+fa	NT 492	$\cdot 10^{-12}$ m^2/s	-	≤ 15.0 / ≤ 18.8	-	-	-	≤ 10.0 / ≤ 12.5	-
	B: I/II+fa+slag			-	≤ 15.0 / ≤ 18.8	-	-	-	≤ 7.4 / ≤ 9.2	-
	C: I/II+fa+sf			-	≤ 15.0 / ≤ 18.8	-	-	-	≤ 6.0 / ≤ 7.5	-
	D: I/II+slag+sf			-	≤ 15.0 / ≤ 18.8	-	-	-	≤ 6.0 / ≤ 7.5	-
	E: I/II+slag			-	Not applicable	-	-	-	Not applicable	-
	F: I/II+slag (<50)			-	≤ 15.0 / ≤ 18.8	-	-	-	Not applicable	-
	G: I/II+sf			-	≤ 15.0 / ≤ 18.8	-	-	-	Not applicable	-
$R_{ACC,0}^{-1}$ (mean/max) [k]		*fib* method	$(mm^2/yr)/(kgCO_2)$	-	-	-	-	-	-	-
Drying shrinkage[l]		ASTM C157	%							
Spalling of concrete in fire		-	-	[m]	[m]	-	-	[m]	-	-
ASR prevention		ASTM C1778	-	Clause 2.1D.3	Clause 2.1D.3	Clause 2.1D.3	-	Clause 2.1D.3	Clause 2.1D.3	Clause 2.1D.3
Thermal control a DEF prevention	Core temperature		°F	176 (80 ºC)						
	Temp diff. ΔT		°F	35 (20 ºC)						
	SO_3 and C_3A[n]		%	$C_3A \leq 8\%$, $SO_3 \leq 3\%$						
Workability [o]				Table 6						
Notes: See subsection 2.2D										

D. Notes to Table 5:

(a) For precast concrete segments refer to Section 317416 “Precast Concrete Tunnel Lining”.

(b) Minimum compressive strength is required for strength. Actual strength may exceed this due to requirements for durability.

(c) Project exposure classes sulfates S0, chlorides from sea XS1-3, chlorides from deicing salts XD1-XD3, carbonation XC1-XC4, freezing-thawing F0-F3.

(d) Permitted cement types and equivalent combinations are given in Table 5. Type I/II can be replaced with Type IV or Type V.

(e) The total cement content includes portland cement and all ground granulated blast furnace slag and pozzolans added to the concrete mixture (such as fly ash, and silica fume).

(f) Air void system is satisfactory when the average spacing factor is ≤ 230 μm, with no single test greater than 260 μm and the air content is > 3.0%. For mixes with w/c ≤ 0.36, the average spacing factor shall not exceed 260 μm, with no single test > 300 μm.

(g) As an alternative to air entrainment prescriptions, equivalent performance shall be demonstrated through freezing and thawing tests of concrete and no-air entrainment. The concrete shall have a durability factor of at least 80% when tested in accordance with procedure A (ASTM C666, Procedure A, 300 cycles), except that the age at testing shall be 56 days. Specimens shall be prisms at least 3 inches. (75 mm) but not more than 5 inches. (125 mm) in width or depth and at least 11 inches. (280 mm) but not more than 16 inches. (400 mm) in length.

(h) When tested to USACE CRD-C48, no passage of water through samples when exposed to a vertical water head equal to 200 psi (460-foot head pressure) for 14 days.

(i) Maximum specified chloride permeability value at 28 days determined in accordance with ASTM C1202.

(j) The chloride migration coefficient $D_{RCM,0}$ values in $\cdot 10^{-12}$ m^2/s determined at 28 days in accordance with Nordtest Build 492.

(k) The inverse effective carbonation resistance values are in $(mm^2/yr)/(kgCO_2)$. Accelerated carbonation test shall be performed in accordance with fib-34, section B.1.2.5.2. The total test duration is 56-days; including 7-days water curing and 21 days air drying in standardized laboratory climate after which shall be placed in a carbonation chamber with a CO_2 concentration of 2.0 vol% for 28 days.

(l) The zero measurement for percent drying shrinkage is the initial measurement taken at demolding of the specimens at 23½±½ hours after introduction of mixing water to the concrete mixture. Measure percent drying shrinkage at the end of specified moist curing period for the structural elements.

(m) Where resistance to explosive spalling of concrete in fire is required, concrete with specified minimum compressive strengths above 40 MPa and w/c ≤ 0.42 shall incorporate monofilament polypropylene fibers conforming to ASTM C1116. Required dosage for polypropylene fibers to be determined by the fire tests (following the requirements of Section 317416 “Precast Concrete Tunnel Lining”) or a minimum dosage of 2.0 kg/m^3 for all remaining structural members subject to risk of explosive spalling.

(n) For concrete subject to elevated curing temperatures, limit the equivalent active alkali content (Na_2O)eq. to 5.0 lb/yd^3 (3.0 kg/m^3) of concrete and adopt the following SO_3 and C_3A limits: $SO_3 \leq 3.5\%$ if $C_3A \leq 3\%$ and $SO_3 \leq 2.5\%$ if $3\% < C_3A \leq 5\%$

(o) Contractor may adjust slump, slump flow and other workability aspects of mixes to suit placement methods while maintaining specified hardened concrete properties. Concrete shall not show visible signs of segregation. In deep sections, when using self-compacting concrete or when placing concrete in special geotechnical works, tests shall be performed to demonstrate a reduced risk of static settlement e.g. HVSI to AASHTO R81.

E. Workability:

1. The Contractor shall select the appropriate slump range that is best suited to the type of work and inform the Designer.
   This section provides guidance on the consistence class and is expressed as slump and slump-flow range appropriate to different uses. Where the concrete is laid on a slope, a lower slump class than that given Table 6 might be necessary.

Table 6: Normal Weight Concrete Slump Test Limits

Type of Work	Slump, inches	Slump Flow, inches
Formed elements: - Sections over 12.0 inches thick - Sections 12.0 inches thick or less	 4 – 6 4 – 6	-
Floors and hand placed pavements Large or industrial floors	4 – 6	-
Sliding formwork construction	1.5 – 4	-
Cast in place piles and drilled shafts not vibrated - Without drilling fluid - With drilling fluid	 7 ± 1 8 ± 1	-
Concrete place under water	8 ± 1	-
Filing for riprap	3 – 7	-
Self-compacting concrete for applications such as congested reinforcement or intricate formwork	-	26 – 29.5

2. Slump can be adjusted using a high range water reducer (superplasticizer) as long as the maximum water/cementitious material ratio is not exceeded. Include the water contained in the aggregates above the amount of absorbed water in the calculation of the water/cementitious material ratio.

2.3 SOURCE QUALITY CONTROL

A. At a minimum, include the following items in the Inspection and Test Plan:

1. Surveillance:
   a. Cement certificates.
   b. Silica fume certificates.
   c. Fly ash certificates.
   d. GGBFS certificates.
   e. Admixture certificates.
   f. Aggregate testing records.
2. Review:
   a. Prequalification plastic and hardened concrete test results.
   b. Mix development report.
3. Verification:
   a. Not used.
4. Witness Point:
   a. Laboratory mix development trials.
   b. Prequalification batching trials.
5. Hold Point:
   a. Not used.

B. Engage a qualified Testing Agency to perform special inspections and to perform independent QC activities as follows:
   1. Twice during mix development, coordinate with Testing Agency to visit the batching plant(s) and/or independent testing laboratory to witness stages of preproduction mix development, including at a minimum, laboratory batching, sampling and sample preparation, and final batching plant trials. Provide test records to the Special Inspector for auditing.
   2. Once per month during production, coordinate with Special Inspector to visit the batching plant(s) and/or independent testing laboratory to witness stages of production, including at a minimum, concrete batching, sampling and sample preparation. Provide the prior month's test records to the Special Inspector for auditing.

C. Batching:
   1. The batching plant requirements for storage and handling of materials, scales, and measuring systems shall be in accordance with ACI 304R.
   2. Mixing equipment, operation of mixers, maintenance of mixers, time and rate of mixing, types of mixers, and testing shall meet the requirements of ACI 304R.
   3. Measuring and batching of materials shall be done at a batching plant. All materials in the concrete mix shall be accurately measured in accordance with ACI 304R.
   4. Portland Cement: Either sacked or bulk cement may be used. No fraction of a sack of cement shall be used in a batch of concrete unless the cement is weighed. Bulk cement shall be weighed on scales separate and distinct from the aggregate hopper or hoppers. Batching shall be such that the accuracy of batching shall be plus or minus one percent of the required weight.
   5. Water: Unless water is to be weighed, the water-measuring equipment shall include an auxiliary tank from which the measuring tank shall be filled. In lieu of the volume method, use of a water-metering device is permitted.
   6. Aggregates:
      a. Aggregates shall be handled from stockpiles or other sources to the batching plant in such a manner as to secure a uniform grading of the material. Aggregates that have become segregated, or mixed with earth or foreign material, shall not be used. Batching shall be so conducted as to result in the weights of material required for each type aggregate within a tolerance of 2 percent.
      b. Free water contents of the coarse and fine aggregates shall be continuously tested and concrete mixture adjusted for moisture conditions of the aggregate in order to meet the designated w/c ratio.
   7. Fine Aggregate: The proportion of fine aggregate shall be between 36 and 44 percent by volume of the total aggregates in the concrete.

D. Mixing:
   1. Ready-mixed concrete shall be either "central mixed" or "shrink mixed" concrete as defined in ASTM C94. "Truck mixed" concrete as defined in ASTM C94 shall not be permitted. Mixing time shall be measured from the time water is added to the mix, or cement contacts the aggregate. All concrete shall be homogeneous and thoroughly mixed, and there shall be no lumps or evidence of undispersed cement. Mixers and agitators, which have an accumulation of hard concrete or mortar, shall not be used. Ready-mixed concrete shall be mixed and transported in accordance with ASTM C94.
   2. The temperature of mixed concrete, immediately before placing shall not be less than 50 deg F or more than 95 deg F. Aggregates and water shall be heated or cooled as necessary to produce concrete within these temperature limits. Neither aggregates nor mixing water shall be heated to exceed 150 deg F.

3. The time elapsing from the time water is added to the mix (or the cement comes in contact with aggregate) until the concrete is deposited in place at the site of the work shall not exceed 60 minutes when the concrete is hauled in non-agitating trucks, nor more than 90 minutes when hauled in truck mixers or truck agitators.
4. The batch shall be so charged into the drum that a portion of the mixing water shall enter in advance of the cement and aggregates. The flow of water shall be uniform and all water shall be in the drum by the end of the first 1/4 of the specified mixing time.
5. Cement shall be charged into the mixer by means that will not result in loss of cement because of the effect of wind, or in accumulation of cement on surfaces of hoppers or in other conditions which reduce or vary the required quantity of cement in the concrete mixture.
6. Air entrainment and chemical admixtures shall be added as solutions. Correct operation of dispensers shall be verified daily.

E. Transporting Mixed Concrete; Mixed Concrete or Truck Mixers:
1. Concrete delivery equipment and control of concrete slump, air content, temperature, and other records shall be in strict accordance with CSA A23.1/A23.2 (ACI 304R).
2. Transporting of mixed concrete shall conform to ASTM C94. Non-agitating delivery equipment shall not be used.
3. Truck agitators shall be loaded not to exceed the manufacturer's guaranteed capacity. They shall maintain the mixed concrete in a thoroughly mixed and uniform mass during hauling.
4. No additional mixing water shall be incorporated into the concrete during hauling or after arrival at the delivery point, unless approved by the Designer. If additional water is to be incorporated into the concrete at the site, the drum shall be revolved not less than 30 revolutions at mixing speed after the water is added and before discharge is commenced. 1 addition of water at the site to adjust mix workability is permitted but the maximum water cement ratio shall not be exceeded. Document and report all additional water added at the plant and at the site.
5. Furnish a water-measuring device in good working condition, mounted on each transit mix truck, for measuring the water added to the mix on the site. All water tanks on transit mix trucks shall be filled prior to being batched and arrive at the construction site one hundred percent (100%) full.
6. Each load of ready mixed concrete delivered at the job shall be accompanied by the ticket in accordance with Delivery, Storage, and Handling.
7. Only the ready-mix concrete manufacturer or designated representative is permitted to add admixtures to the concrete on-site. Admixtures added to the mix at the construction site shall be measured to the precise amounts listed in the approved mix design. The delivery ticket shall be reviewed so the amount of admixture added on-site is proportional to the size of the load. After the addition of the admixture, the concrete shall be mixed in the truck to uniformly distribute the admixture. The amount and type of admixture added on-site shall be recorded on the delivery ticket and retained for submittal to the Company.

PART 3 - EXECUTION

3.1 PREPARATION

A. Refer to Section 033000 “Cast-In-Place Concrete”.

3.2 PLACEMENT

A. Refer to Section 033000 “Cast-In-Place Concrete”.

3.3 CONSOLIDATION

A. Refer to Section 033000 “Cast-In-Place Concrete”.

3.4 OPENINGS, INSERTS, EMBEDDED ITEMS

A. Refer to Section 033000 “Cast-In-Place Concrete”.

3.5 FIELD QUALITY CONTROL

A. At a minimum, include the following items in the Inspection and Test Plan:
   1. Surveillance:
      a. Not used.
   2. Review:
      a. Hardened concrete test results.
   3. Verification:
      a. Not used.
   4. Witness Point:
      a. Plastic concrete testing results prior to concrete placement.
   5. Hold Point:
      a. Review and acceptance of concrete mix designs by Company.

B. Special Inspector: Provide access for the Special Inspector to perform independent QC activities as follows:
   1. Weekly during construction, coordinate with Special Inspector to visit the project site(s) and independent testing laboratory to witness field inspection and testing. Provide the prior week’s test records to the Special Inspector for auditing.

C. Concrete tests shall be performed by an approved independent Testing Agency. The test reports shall be forwarded by the testing laboratory directly to the Company upon receipt.

D. Concrete Tests: Testing of composite samples of fresh concrete obtained according to ASTM C172 shall be performed according to the following requirements:
   1. Testing Frequency: Obtain one composite sample for each day's pour of each concrete mixture exceeding 5 cu. yd., but less than 25 cu. yd., plus one set for each additional 50 cu. yd. or fraction thereof. When frequency of testing provides fewer than five

compressive-strength tests for each concrete mixture, testing shall be conducted from at least five randomly selected batches or from each batch if fewer than five are used.

2. Slump: ASTM C143; one test at point of placement for each composite sample, but not less than one test for each day's pour of each concrete mixture. Perform additional tests when concrete consistency appears to change. Concrete that has been rejected for failing to meet the slump requirements shall not be used.
3. Air Content: ASTM C231 pressure method, for normal-weight concrete; one test for each composite sample, but not less than one test for each day's pour of each concrete mixture.
4. Concrete Temperature: ASTM C1064; one test hourly when air temperature is 40 deg F and below or 80 deg F and above, and one test for each composite sample.
5. Compression Test Specimens: ASTM C31;
    a. Cast and laboratory cure four standard cylinder specimens for each composite sample.
    b. Cast and field cure four standard cylinder specimens for each composite sample.
6. Compressive-Strength Tests: ASTM C39;
    a. Test one laboratory-cured specimen at 7 days and one set of two specimens at 28 days.
    b. Test one field-cured specimen at 7 days and one set of two specimens at 28 days.
    c. Test additional sample as requested by the Company.
    d. A compressive-strength test shall be the average compressive strength from a set of two specimens obtained from same composite sample and tested at age indicated.
7. When strength of field-cured cylinders is less than 85 percent of companion laboratory-cured cylinders, evaluate operations and provide corrective procedures for protecting and curing in-place concrete.
8. Strength of each concrete mixture will be satisfactory if every average of any three consecutive compressive-strength tests equals or exceeds specified compressive strength and no compressive-strength test value falls below specified compressive strength by more than 500 psi.
9. Test results shall be reported in writing to within 48 hours of testing. Reports of compressive-strength tests shall contain project identification name and number, date of concrete placement, name of concrete Testing Agency, location of concrete batch in work, design compressive strength at 28 days, concrete mixture proportions and materials, compressive breaking strength, and type of break for both 7- and 28-day tests.
10. Nondestructive Testing: Impact hammer, sonoscope, or other nondestructive device may be permitted by Company but will not be used as sole basis for approval or rejection of concrete.
11. Additional Tests: Testing Agency shall make additional tests of concrete when test results indicate that slump, air entrainment, compressive strengths, or other requirements have not been met, as directed by Company. Testing Agency may conduct tests to determine adequacy of concrete by cored cylinders complying with ASTM C42 or by other methods as directed by Company.
12. Additional testing and inspecting will be performed to determine compliance of replaced or additional work with specified requirements.
13. Correct deficiencies in the work that test reports and inspections indicate do not comply with the Agreement and Exhibits.

Table 7: Sampling, Testing, and Acceptance Requirements

Material or Product (Subsection)	Type of Acceptance (Subsection)	Characteristic	Test Methods Specifications	Sampling Frequency	Point of Sampling	Split Sample	Reporting Time	Remarks
Source								
Aggregate 2.1D	Measured and tested for conformance	Quality	Subsection 2.1D	1 per material type	Source of material	Yes	Before producing	–
Mix Design								
Concrete composition	"	All	Subsection 2.2	1 per mix design	"	If requested	"	–
Production Start-up								
Durability	Measured and tested for conformance [a]	Compressive strength [b] [c] Air void system [d] Freezing and Thawing resistance [e] Maximum chloride permeability [f] Maximum chloride migration coef. [g] Drying shrinkage [h]	ASTM C31, ASTM C39 ASTM C457 ASTM C666 ASTM C1202 NT Build 492 ASTM C157	1 set per mix design	Discharge stream at point of placement	If requested	Upon completing tests	–
Production								
Produced aggregate (fine & coarse)	Measured and tested for conformance	Gradation	MTM 109	1 per day	Flowing aggregate stream (bin, belt, discharge conveyor belt, or stockpile)	Yes	Before batching	–
		Fineness modulus	MTM 109	–	"	"	"	–
		Moisture test	AASHTO T 255/ASTM C566	–	"	"	"	–

(a) Sample according to AASHTO R 60, except composite samples are not required.
(b) Cast at least four compressive strength test cylinders for 6- by 12-inch (150- by 300-millimeter) specimens or six compressive strength cylinders for 4- by 8-inch (100- by 200-millimeter) and carefully transport the cylinders to the job site curing facility.
(c) A single compressive strength test result is the average result from two 6- by 12-inch (150- by 300-millimeter) or three 4- by 8-inch (100- by 200-millimeter) cylinders cast from the same load.
(d) The test sample used for the microscopic air-void analysis shall be made from a trial concrete batch, vibrated into a cylinder mould so as to represent the level of vibration of the production concrete in the forms. The concrete mix design information shall include one microscopic air-void analysis performed by an independent testing laboratory in order to determine the spacing factor of the hardened concrete. If adjustments to the mix design are necessary, the air void analysis shall be repeated. An air-void spacing factor shall be determined in accordance with ASTM C457 modified point count method at 100 times magnification.

Table 7 (continued): Sampling, Testing, and Acceptance Requirements

Material or Product (Subsection)	Type of Acceptance (Subsection)	Characteristic	Category	Test Methods Specifications	Sampling Frequency	Point of Sampling	Split Sample	Reporting Time	Remarks
Production (continued)									
Concrete	Measured and tested for conformance	Density		ASTM C138	1 per load after at least 0.25CY (0.2 m^3) is discharged(i)	Point of discharge	No	Upon completing tests	–
		Air content		ASTM C138	"	"	No	"	–
		Slump (j)		ASTM C143	"	"	No	"	–
		Temperature		ASTM C1064	"	"	No	"	–
Concrete	Statistical	Compressive strength(b)(c) (28-day) or other-wise stated in plans		ASTM C31, ASTM C39	1 set per 30 CY (25 m^3),but not less than 1 per day and not less than 5 sets total	Discharge stream at point of placing	Yes	28 days	Deliver verification cylinders to designated laboratory for testing
Durability	Statistical	Air void system (d)		ASTM C457	1 set per 260 yd^3 (200 m^3), but not less than 1 per month and not less than 5 sets total	Discharge stream at point of placement	If requested	Upon complet-ing tests	–
		Maximum chloride permeability (f)		ASTM C1202					
		Maximum chloride migration coef. (g)		NT Build 492					

(e) Satisfactory freeze-thaw durability shall be substantiated by proper air-entrainment or demonstration that the durability factor is achieved. Preconstruction testing shall be conducted to demonstrate that the concrete is resistant to freezing and thawing on at least 3 samples in accordance with ASTM C666/C666M.

(f) Cast at least three 4- by 8-inch (100- by 200-millimeter) maximum chloride permeability cylinders per set and carefully transport the cylinders to the job site curing facility. Cure the cylinders for 7 days according to AASHTO M 201. Then cure at 100 °F ± 10 °F (38 °C ± 5 °C) in saturated lime water until ASTM C1202 sample conditioning begins. Have the testing done at 28 days in an independent laboratory that is qualified to perform the testing. The set test result is the average of the measurements on three cylinders cast from the same load. Adjust production test result by the average difference. Report both initial and adjusted test result.

(g) Cast at least three cylinders per set for determination of chloride migration coefficient in accordance with NT Build 492. Test samples at 28 days of age.

(h) If testing is required, use 3- by 3- by 11-inch (75- by 75- by 275-millimeter) prisms for drying shrinkage specimens. Cast at least three drying shrinkage prisms per set and carefully transport the prisms to the job site curing facility. Moist the prisms for the duration of the specified moist curing period. Have the testing done in an independent laboratory that is qualified to perform the testing. The zero measurement for percent drying shrinkage is the initial measurement taken at demolding of the specimens at 23½±½ hours after introduction of mixing water to the concrete mixture. Measure percent drying shrinkage at the end of specified moist curing period for the structural elements, 1, 4, 7, 14, 28, and 56 days after the end of the specified field moist curing period. Drying shrinkage 28 days after the termination of moist curing (28 days drying) cannot exceed 60 percent of the maximum specified value. The set drying shrinkage test result is the average result from three prisms cast from the same load.

(i) If three successive samples are tested and compliance to the specifications is indicated, screening tests may be reduced to an approved frequency. Resume initial testing frequency if a test shows a failing temperature, air content, slump, or when directed.

(j) If the point of placement is different from the point of discharge, correlate the discharge tests with the placement tests to document the changes.

E. Periodic Special Inspections:
   1. None.

F. Continuous Special Inspections:
   1. Fabricate specimens for strength tests.
   2. Slump, air content, temperature of concrete.

G. Inspection and Test Plan for acceptance of works:
   1. Submit Inspection and Test Plan using Table 7 as a template for sampling, testing, and propose acceptance requirements derived from the criteria listed in Table 5.
      a. Control the concrete cover over reinforcement using electromagnetic cover meter or GPR equipment in surfaces exposed to de-icing salts at a 10-inch grid spacing.
      b. Furnish production certifications with each shipment cementitious material.
      c. Concrete compressive strength, flexural or residual flexural strengths for fiber reinforced concrete shall be evaluated using the characteristic strength requirement. The lower specification limit is the minimum required compressive strength at 28 days (fc') specified in the drawings.

END OF SECTION 033100

SECTION 034100 - PRECAST STRUCTURAL CONCRETE

PART 1 - GENERAL

1.1 SUMMARY

A. Section includes fabrication and installation of the precast structural concrete sump roadway units (Company designed). Requirements for the Precast Concrete Tunnel Lining and Precast Permanent Access Tunnel units are not included in this Section.

B. Related Requirements:
1. Section 033000 "Cast-in-Place Concrete" for placing connection anchors in concrete.
2. Section 033100 “Structural Concrete Materials” for concrete mix design requirements.

1.2 DEFINITIONS

A. Design Reference Sample: Sample of approved precast structural concrete finish, and texture, preapproved by Company.

1.3 REFERENCES

A. American Association of State Highway Transportation Officials (AASHTO):
1. AASHTO M 251 Standard Specification for Plain and Laminated Elastomeric Bridge Bearings.

B. American Concrete Institute (ACI):
1. ACI 216.1 Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies.
2. ACI 318 Building Code Requirements for Structural Concrete.
3. Refer to Sections 033000 and 033100 for additional ACI references.

C. ASTM International (ASTM):
1. ASTM A27 Standard Specification for Steel Castings, Carbon, for General Application.
2. ASTM A47 Standard Specification for Ferritic Malleable Iron Castings.
3. ASTM A108 Standard Specification for Steel Bar, Carbon and Alloy, Cold-Finished.
4. ASTM A123 Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products.
5. ASTM A153 Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware.
6. ASTM A283 Standard Specification for Low and Intermediate Tensile Strength Carbon Steel Plates.
7. ASTM A307 Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60 000 PSI Tensile Strength.

8. ASTM A563 Standard Specification for Carbon and Alloy Steel Nuts.
9. ASTM A572 Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel.
10. ASTM A615 Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement.
11. ASTM A706 Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement.
12. ASTM A767 Standard Specification for Zinc-Coated (Galvanized) Steel Bars for Concrete Reinforcement.
13. ASTM A775 Standard Specification for Epoxy-Coated Steel Reinforcing Bars.
14. ASTM A780 Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings.
15. ASTM A1064 Standard Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete.
16. ASTM C42 Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete.
17. ASTM C881 Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete.
18. ASTM C1107 Standard Specification for Packaged Dry, Hydraulic-Cement Grout (Nonshrink).
19. ASTM C1218 Standard Test Method for Water-Soluble Chloride in Mortar and Concrete.
20. ASTM C1610 Standard Test Method for Static Segregation of Self-Consolidating Concrete Using Column Technique.
21. ASTM C1611 Standard Test Method for Slump Flow of Self-Consolidating Concrete.
22. ASTM C1621 Standard Test Method for Passing Ability of Self-Consolidating Concrete by J-Ring.
23. ASTM C1712 Standard Test Method for Rapid Assessment of Static Segregation Resistance of Self-Consolidating Concrete Using Penetration Test.
24. ASTM D412 Standard Test Methods for Vulcanized Rubber and Thermo Plastic Elastomers – Tension.
25. ASTM D2240 Standard Test Method for Rubber Property – Durometer Hardness.
26. ASTM E165 Standard Practice for Liquid Penetrant Testing for General Industry.
27. ASTM E709 Standard Guide for Magnetic Particle Testing.
28. ASTM E1444 Standard Practice for Magnetic Particle Testing.
29. ASTM F844 Standard Specification for Washers, Steel, Plain (Flat), Unhardened for General Use.
30. ASTM F3125 Standard Specification for High Strength Structural Bolts and Assemblies.

D. American Welding Society (AWS):
1. AWS D1.1 Structural Welding Code – Steel.
2. AWS D1.4 Structural Welding Code – Reinforcing Steel.
3. AWS C5.4 Recommended Practices for Stud Welding.

E. Precast/Prestressed Concrete Institute (PCI):
1. PCI MNL-116 Manual for Quality Control for Plants and Production of Structural Precast Concrete Products.
2. PCI MNL-124 Design for Fire Resistance of Precast Prestressed Concrete.
3. PCI MNL-127 PCI Erector's Manual - Standards and Guidelines for the Erection of Precast Concrete Products.
4. PCI MNL-135 Tolerance Manual for Precast and Prestressed Concrete Construction.
5. PCI TR-6 Guidelines for the Use of Self-Consolidating Concrete in Precast/Prestressed Concrete.

F. Federal Specification MIL-P-21035B: Paint high zinc dust content, galvanizing repair.

G. International Concrete Repair Institute (ICRI):
1. ICRI Guideline No. 310.2 Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays.

H. Michigan Department of Transportation (MDOT):
1. MDOT Standard Specifications for Construction.

I. Research Council on Structural Connections (RCSC):
1. Specification for Structural Joints Using High Strength Bolts.

J. The Society for Protective Coatings (SSPC):
1. SSPC-PAINT #20 Organic Zinc Rich Primer, Type II.

1.4 PRECONSTRUTION MEETINGS

A. Preconstruction Conference: Conduct conference at precast facility site at least two weeks prior to start of production.

B. Preinstallation Meeting: Conduct conference at project site at least two weeks prior to start of installation.

1.5 ACTION SUBMITTALS

A. Product Data: For each type of product.

B. Design Mixtures: Refer to Section 033100 “Structural Concrete Materials”.

C. Repair Procedures:
1. Submit repair procedures for all types of repairs intended to be used in plant and field.

D. Shop Drawings:
1. Include member locations, plans, elevations, dimensions, shapes and sections, openings, support conditions, and types of reinforcement, including special reinforcement.
2. Detail fabrication and installation of precast structural concrete units, including connections at member ends and to adjoining construction.
3. Indicate joints, reveals, drips, chamfers, and extent and location of each surface finish.
4. Detail loose and cast-in hardware, lifting and erection inserts, connections, and joints.
5. Indicate locations, tolerances, and details of anchorage devices to be embedded in or attached to structure or other construction.
6. Include and locate all openings.
7. Indicate location of each precast structural concrete unit by same identification mark placed on panel.
8. Indicate relationship of precast structural concrete units to adjacent materials.
9. Indicate shim sizes and grouting sequence.
10. If design modifications are proposed to meet performance requirements and field conditions, submit design calculations and Shop Drawings. Do not adversely affect the

appearance, durability, or strength of units when modifying details or materials and maintain the general design concept.

E. Samples:
1. For each type of finish indicated on exposed surfaces of precast structural concrete units, in sets of three, representative of finish and texture variations expected; approximately 12 by 12 by 2 inches.

1.6 INFORMATIONAL SUBMITTALS

A. Qualification Data: For fabricator.

B. Welding certificates.

C. Material certificates for the following:
1. Reinforcing materials.
2. Bearing pads.
3. Structural-steel shapes and hollow structural sections.
4. For aggregates, cementitious materials and concrete admixtures refer to Section 033100 “Structural Concrete Materials”.

D. Preconstruction test reports.

E. Source quality-control reports.

F. Repair reports.

G. Field quality-control and special inspection reports.

1.7 QUALITY ASSURANCE

A. Qualifications:
1. Fabricator:
   a. Designated as a PCI-certified plant as follows: Group C, category C1 - precast concrete products (no prestressed reinforcement).
   b. Immediately correct items that do not conform to PCI plant certification. Provide a copy of conformance to the Company before beginning production.
   c. Provide inspection facilities in accordance with Section 809 and subsection 707.03.A.2 of the MDOT standard specifications for construction.
2. Installer:
   a. A precast concrete erector qualified and designated by PCI's certificate of compliance, to erect category S1 - simple structural systems.
3. Field Auditor:
   a. An experienced precast concrete erector who has retained a "PCI-Certified Field Auditor" to conduct a field audit of a project installed by erector in category S1 - simple structural systems and who can produce an erectors' post audit declaration, according to PCI MNL-127, "PCI Erector's Manual - Standards and Guidelines for the Erection of Precast Concrete Products."
4. Maintain qualifications and certification for duration of the Agreement and Exhibits.

B. Quality-Control Standard: For manufacturing procedures, testing requirements, and quality-control recommendations for types of units required, comply with PCI MNL 116, "Manual for Quality Control for Plants and Production of Structural Precast Concrete Products."

C. Welding Qualifications: Qualify procedures and personnel according to AWS D1.1 and AWS D1.4.

D. Sample Panels: After sample approval and before fabricating precast structural concrete units, produce a minimum of two sample panels approximately 16 sq. ft. in area for review by Company. Incorporate full-scale details of finishes, textures, and transitions in sample panels.
   1. Locate panels where indicated or, if not indicated, as directed by Company.
   2. Damage part of an exposed-face surface for each finish and texture, and demonstrate adequacy of repair techniques proposed for repair of surface blemishes.
   3. After approval of repair technique, maintain one sample panel at fabricator's plant and one at project site in an undisturbed condition as a standard for judging the completed work.
   4. Demolish and remove sample panels when directed.

1.8 PRECONSTRUCTION TESTING

A. Not used.

1.9 DELIVERY, STORAGE, AND HANDLING

A. Furnish loose connection hardware and anchorage items to be embedded in or attached to other construction before starting that work. Provide locations, setting diagrams, templates, instructions, and directions, as required, for installation.

B. Support units during shipment on nonstaining shock-absorbing material in same position as during storage.

C. Store units with adequate bracing and protect units to prevent contact with soil, to prevent staining, and to prevent cracking, distortion, warping or other physical damage.
   1. Store units with dunnage across full width of each bearing point unless otherwise indicated.
   2. Place adequate dunnage of even thickness between each unit.
   3. Place stored units so identification marks are clearly visible, and units can be inspected.

D. Handle and transport units in a manner that avoids excessive stresses that cause cracking or damage.

E. Lift and support units only at designated points indicated on Shop Drawings.

1.10 FIELD CONDITIONS

A. Not used.

PART 2 - PRODUCTS

2.1 PERFORMANCE REQUIREMENTS

A. Structural Performance: Precast structural concrete units and connections shall withstand design loads indicated within limits and under conditions indicated.

2.2 MOLD MATERIALS

A. Molds: Rigid, dimensionally stable, non-absorptive material, warp and buckle free, that provides continuous precast concrete surfaces within fabrication tolerances indicated; nonreactive with concrete and suitable for producing required finishes.
   1. Mold-Release Agent: Commercially produced form-release agent that does not bond with, stain, or adversely affect precast concrete surfaces and does not impair subsequent surface or joint treatments of precast concrete.

B. Surface Retarder: Chemical set retarder, capable of temporarily delaying setting of newly placed concrete mixture to depth of reveal specified.

2.3 REINFORCING MATERIALS

A. Reinforcing Bars: ASTM A615, Grade 60, deformed.

B. Low-Alloy-Steel Reinforcing Bars: ASTM A706, deformed.

C. Galvanized Reinforcing Bars: ASTM A615, Grade 60, ASTM A706 deformed bars, with ASTM A767 Class II zinc coating and chromate treatment. Galvanize after fabrication and bending.

D. Supports: Suspend reinforcement from back of mold or use bolsters, chairs, spacers, and other devices for spacing, supporting, and fastening reinforcing bars and welded wire reinforcement in place according to PCI MNL 116.

2.4 CONCRETE MATERIALS

A. Refer to Section 033100 “Structural Concrete Materials”.

2.5 STEEL CONNECTION MATERIALS

A. Carbon-Steel Shapes and Plates: ASTM A572 Grade 50.

B. Carbon-Steel-Headed Studs: ASTM A108, Grade 1010 through 1020, cold finished, AWS D1.1 Type A or B, with arc shields and with minimum mechanical properties of PCI MNL 116.

C. Malleable-Iron Castings: ASTM A47 Grade 32510 or Grade 35028.

D. Carbon-Steel Castings: ASTM A27 Grade 60-30.

E. High-Strength, Low-Alloy Structural Steel: ASTM A572.

F. Deformed-Steel Wire or Bar Anchors: ASTM A1064 or ASTM A706.

G. Carbon-Steel Bolts and Studs: ASTM A307, Grade A; carbon-steel, hex-head bolts and studs; carbon-steel nuts, ASTM A563; and flat, unhardened steel washers, ASTM F844.

H. Zinc-Coated Finish: For exterior steel items, steel exposed at surface of precast, and items indicated for galvanizing, apply zinc coating by hot-dip process according to ASTM A123 or ASTM A153.
   1. For steel shapes, plates, and tubing to be galvanized, limit silicon content of steel to less than 0.03 percent or to between 0.15 and 0.25 percent or limit sum of silicon and 2.5 times phosphorous content to 0.09 percent.
   2. Galvanizing Repair Paint: High-zinc-dust-content paint with dry film containing not less than 94 percent zinc dust by weight, and complying with MIL-P-21035B or SSPC-Paint 20.

I. Welding Electrodes: Comply with AWS standards.

J. Precast Accessories: Provide clips, hangers, plastic or steel shims, and other accessories required to install precast structural concrete units.

2.6 BEARING PADS

A. Provide one of the following bearing pads for precast structural concrete units as recommended by precast fabricator for application:
   1. Elastomeric Pads: AASHTO M 251, plain, vulcanized, 100 percent polychloroprene (neoprene) elastomer, molded to size or cut from a molded sheet, 50 to 70 Shore, Type A durometer hardness, ASTM D2240; minimum tensile strength 2250 psi, ASTM D412.

2.7 ACCESSORIES

A. Precast Accessories: Provide clips, hangers, high-density plastic or hot dip galvanized steel shims, and other accessories required to install structural precast concrete units.

2.8 GROUT MATERIALS

A. Nonmetallic, Nonshrink Grout: Packaged, nonmetallic, noncorrosive, nonstaining grout containing selected silica sands, portland cement, shrinkage-compensating agents, plasticizing and water-reducing agents, complying with ASTM C1107 Grade A for drypack and Grades B and C for flowable grout and of consistency suitable for application within a 30-minute working time. Water-soluble chloride ion content less than 0.06 percent by weight of cement when tested according to ASTM C1218.

B. Epoxy-Resin Grout: Two-component, mineral-filled epoxy resin; ASTM C881, of type, grade, and class to suit requirements.

2.9 CONCRETE MIXTURES

A. Refer to Section 033100 “Structural Concrete Materials”. Prepare design mixtures for each type of precast concrete required.

2.10 MOLD FABRICATION

A. Molds: Accurately construct molds, tight, of sufficient strength to withstand pressures due to concrete-placement operations and temperature changes. Coat contact surfaces of molds with release agent before reinforcement is placed. Avoid contamination of reinforcement and prestressing tendons by release agent.

B. Maintain molds to provide completed precast structural concrete units of shapes, lines, and dimensions indicated, within fabrication tolerances specified.

C. Edge and Corner Treatment: Uniformly chamfered.

2.11 FABRICATION

A. Cast-in Anchors, Inserts, Plates, Angles, and Other Anchorage Hardware: Fabricate anchorage hardware with sufficient anchorage and embedment to comply with design requirements. Accurately position for attachment of loose hardware, and secure in place during precasting operations. Locate anchorage hardware where it does not affect position of main reinforcement or concrete placement.
   1. Weld-headed studs and deformed bar anchors used for anchorage according to AWS D1.1 and AWS C5.4.

B. Furnish loose hardware items including steel plates, clip angles, seat angles, anchors, dowels, cramps, hangers, and other hardware shapes for securing precast structural concrete units to supporting and adjacent construction.

C. Cast-in all openings. Do not drill or cut openings or prestressing strand without Company's approval.

D. Reinforcement: Comply with recommendations in PCI MNL-116 for fabricating, placing, and supporting reinforcement.
   1. Clean reinforcement of loose rust and mill scale, earth, and other materials that reduce or destroy the bond with concrete. When damage to epoxy-coated reinforcement exceeds limits specified in ASTM A775, repair with patching material compatible with coating material and epoxy coat bar ends after cutting.
   2. Accurately position, support, and secure reinforcement against displacement during concrete-placement and consolidation operations. Completely conceal support devices to prevent exposure on finished surfaces.
   3. Place reinforcing steel and prestressing strand to maintain at least 1-1/2 inches minimum concrete cover. Arrange, space, and securely tie bars and bar supports to hold reinforcement in position while placing concrete. Direct wire tie ends away from finished, exposed concrete surfaces.

E. Reinforce precast structural concrete units to resist handling, transportation, and erection stresses and specified in-place loads.

F. Comply with requirements in PCI MNL-116 and in this Section for measuring, mixing, transporting, and placing concrete. After concrete batching, no additional water may be added.

G. Place concrete in a continuous operation to prevent cold joints or planes of weakness from forming in precast concrete units.

H. Thoroughly consolidate placed concrete by vibration without dislocating or damaging reinforcement and built-in items, and minimize pour lines, honeycombing, or entrapped air voids on surfaces. Use equipment and procedures complying with PCI MNL-116.
   1. Place self-consolidating concrete without vibration according to PCI TR-6. Ensure adequate bond between face and backup concrete, if used.

I. Comply with PCI MNL-116 procedures for hot- and cold-weather concrete placement.

J. Identify pickup points of precast structural concrete units and orientation in structure with permanent markings, complying with markings indicated on Shop Drawings. Imprint or permanently mark casting date on each precast structural concrete unit on a surface that does not show in finished structure.

K. Cure concrete, according to requirements in PCI MNL-116, by moisture retention without heat or by accelerated heat curing using live steam or radiant heat and moisture. Cure units until compressive strength is high enough to ensure that stripping does not have an effect on performance or appearance of final product.

L. Discard and replace precast structural concrete units that do not comply with requirements, including structural, manufacturing tolerance, and appearance, unless repairs meet requirements in PCI MNL-116 and meet Company's approval.

2.12 FABRICATION TOLERANCES

A. Fabricate precast structural concrete units to shapes, lines, and dimensions indicated so each finished unit complies with PCI MNL-116 product dimension tolerances as well as position tolerances for cast-in items.

2.13 COMMERCIAL FINISHES

A. Grade B Finish: Fill air pockets and holes larger than 1/2 inch in diameter or depth with structural repair material. Air holes less than 1/4 inch deep, water marks, and color variations are permitted.

B. Screed or float finish unformed surfaces. Strike off and consolidate concrete with vibrating screeds to a uniform finish. Hand screed at projections. Normal color variations, minor indentations, minor chips, and spalls are permitted. Major imperfections, honeycombing, or defects are not permitted.

C. Apply roughened surface finish according to ACI 318 (equivalent to CSP 10 as described in ICRI Guideline No. 310.2) to precast concrete units that will be grouted or seated on mortar during or after installation.

2.14 SOURCE QUALITY CONTROL

A. At a minimum, include the following items in the Inspection and Test Plan:
   1. Surveillance:
      a. Mold cleanliness after preparation.
      b. Proper application of release agent.
      c. Concrete placement and consolidation.
      d. Concrete surface finishing.
      e. Curing procedures.
   2. Review:
      a. Concrete test results.
   3. Verification:
      a. Temperature measurement during curing.
   4. Witness Point:
      a. Not used.
   5. Hold Point:
      a. Reinforcing steel and embedments properly placed and secured in mold.

B. In accordance with Section 033100 “Structural Concrete Materials”.

C. Engage a qualified Testing Agency to perform tests and inspections.

D. Once per month during production, coordinate with Testing Agency to visit the precast plant and/or independent testing laboratory to witness stages of production, including at a minimum, concrete casting, sampling and sample preparation. Provide the prior month’s test records to the Testing Agency for auditing.

E. Testing Agency shall report test results promptly and in writing to Contractor and Company.

F. Testing:
   1. Test and inspect precast structural concrete according to PCI MNL 116 requirements and ASTM C1610, ASTM C1611, ASTM C1621, and ASTM C1712.
   2. Test and inspect self-consolidating concrete according to PCI TR-6.

G. Strength of precast structural concrete units is considered deficient if units fail to comply with ACI 318 requirements for concrete strength.

H. If there is evidence that strength of precast concrete units may be deficient or may not comply with ACI 318 requirements, employ a qualified Testing Agency to obtain, prepare, and test cores drilled from hardened concrete to determine compressive strength according to ASTM C42.
   1. Take a minimum of three representative cores from units of suspect strength, from locations directed by Company. Do not cut reinforcement when coring. Preplan locations to avoid reinforcing.
   2. Test cores in an air-dry condition or, if units are wet under service conditions, test cores after immersion in water in a wet condition.

3. Strength of concrete for each series of three cores is considered satisfactory if average compressive strength is equal to at least 85 percent of 28-day design compressive strength and no single core is less than 75 percent of 28-day design compressive strength.
4. Report test results in writing on same day that tests are performed, with copies to Company, Contractor, and precast concrete fabricator. Test reports include the following:
    a. Project identification name and number.
    b. Date when tests were performed.
    c. Name of precast concrete fabricator.
    d. Name of concrete Testing Agency.
    e. Identification letter, name, and type of precast concrete unit(s) represented by core tests; design compressive strength; type of break; compressive strength at breaks, corrected for length-diameter ratio; and direction of applied load to core in relation to horizontal plane of concrete as placed.

I. Patching: If core test results are satisfactory and precast structural concrete units comply with requirements, clean and dampen core holes and solidly fill with same precast concrete mixture that has no coarse aggregate, and finish to match adjacent precast concrete surfaces.

J. Defective Units: Discard and replace precast structural concrete units that do not comply with requirements, including strength, manufacturing tolerances, and color and texture range. Chipped, spalled, or cracked units may be repaired, subject to Company's approval. Company reserves the right to reject precast units that do not match approved samples, sample panels, and mockups. Replace unacceptable units with precast concrete units that comply with requirements.

PART 3 - EXECUTION

3.1 EXAMINATION

A. Examine supporting structural frame or foundation and conditions for compliance with requirements for installation tolerances, bearing surface tolerances, and other conditions affecting performance of the work.

B. Proceed with installation only after unsatisfactory conditions have been corrected.

C. Do not move precast concrete members to storage until concrete has reached a minimum of 75% of the design 28-day compressive strength.

D. Do not install precast concrete members until concrete has reach the minimum 28-day compressive strength.

E. Do not install precast concrete units until supporting, cast-in-place concrete has attained minimum allowable design compressive strength (minimum 28-day compressive strength) and until supporting steel or other structure is structurally ready to receive loads from precast concrete units.

3.2 INSTALLATION

A. Install clips, hangers, bearing pads, and other accessories required for connecting precast structural concrete units to supporting members and backup materials.

B. Erect precast structural concrete level, plumb, and square within specified allowable tolerances. Provide temporary structural framing, shoring, and bracing as required to maintain position, stability, and alignment of units until permanent connections are complete.
   1. Install temporary steel or plastic spacing shims or bearing pads as precast structural concrete units are being erected. Tack weld steel shims to each other to prevent shims from separating.
   2. Maintain horizontal and vertical joint alignment and uniform joint width as erection progresses.
   3. Remove projecting lifting devices and use plastic patch caps or sand-cement grout to fill voids within recessed lifting devices flush with surface of adjacent precast surfaces when recess is exposed.

C. Connect precast structural concrete units in position by bolting, welding, grouting, or as otherwise indicated on Shop Drawings. Remove temporary shims, wedges, and spacers as soon as practical after connecting and grouting are completed.
   1. Do not permit connections to disrupt continuity of roof flashing.

D. Field cutting of precast units is not permitted without approval of the Company.

E. Fasteners: Do not use drilled or powder-actuated fasteners for attaching accessory items to precast, prestressed concrete units.

F. Welding: Comply with applicable requirements in AWS D1.1 and AWS D1.4 for welding, welding electrodes, appearance, quality of welds, and methods used in correcting welding work.
   1. Protect precast structural concrete units and bearing pads from damage by field welding or cutting operations, and provide noncombustible shields as required.
   2. Clean weld-affected steel surfaces with chipping hammer followed by brushing, and apply a minimum 4.0-mil-thick coat of galvanized repair paint to galvanized surfaces according to ASTM A780.
   3. Visually inspect welds and remove, reweld, or repair incomplete and defective welds.

G. At bolted connections, use lock washers, tack welding, or other approved means to prevent loosening of nuts after final adjustment.
   1. Where slotted connections are used, verify bolt position and tightness. For sliding connections, properly secure bolt but allow bolt to move within connection slot.
   2. For slip-critical connections, use one of the following methods to assure proper bolt pretension:
      a. Turn-of-Nut: According to RCSC's "Specification for Structural Joints Using High Strength Bolts."
      b. Calibrated Wrench: According to RCSC's "Specification for Structural Joints Using High Strength Bolts.
      c. Twist-off Tension Control Bolt: ASTM F3125, Grade 1852.
      d. Direct-Tension Control Bolt: ASTM F3125, Grade 1852.
   3. For slip-critical connections, use method and inspection procedure approved by Company and coordinated with inspection agency.

H. Grouting or Dry-Packing Connections and Joints: Grout connections and joints and open spaces at keyways, connections, and joints where required or indicated on Shop Drawings. Retain flowable grout in place until hard enough to support itself. Alternatively, pack spaces with stiff dry-pack grout material, tamping until voids are completely filled.
   1. Place grout and finish smooth, level, and plumb with adjacent concrete surfaces.
   2. Fill joints completely without seepage to other surfaces.
   3. Trowel top of grout joints on roofs smooth and uniform. Finish transitions between different surface levels not steeper than 1 to 12.
   4. Promptly remove grout material from exposed surfaces before it affects finishes or hardens.
   5. Keep grouted joints damp for not less than 24 hours after initial set.

3.3 ERECTION TOLERANCES

A. Erect precast structural concrete units level, plumb, square, and in alignment without exceeding the noncumulative erection tolerances of PCI MNL-135.

B. Minimize variations between adjacent slab members by jacking, loading, or other method recommended by fabricator and approved by Company.

3.4 REPAIRS

A. Repair precast structural concrete units in accordance with PCI requirement for repairs approved by the Company. All repairs are structural.
   1. Prequalified repairs may be permitted if structural adequacy, serviceability, durability, and appearance of units have not been impaired.

B. Prepare and repair damaged galvanized coatings with galvanizing repair paint according to ASTM A780.

C. Remove and replace damaged precast structural concrete units that cannot be repaired or when repairs do not comply with requirements as determined by the Company.

3.5 CLEANING

A. Clean mortar, plaster, fireproofing, weld slag, and other deleterious material from concrete surfaces and adjacent materials immediately.

B. Clean exposed surfaces of precast concrete units after erection and completion of joint treatment to remove weld marks, other markings, dirt, and stains.
   1. Perform cleaning procedures, if necessary, according to precast concrete fabricator's written recommendations. Protect other work from staining or damage due to cleaning operations.
   2. Do not use cleaning materials or processes that could change the appearance of exposed concrete finishes or damage adjacent materials.

3.6 FIELD QUALITY CONTROL

A. At a minimum, include the following items in the Inspection and Test Plan:
   1. Surveillance:
      a. Examination of structural frame and foundation.
      b. Installation of precast units.
      c. Repairs.
      d. Cleaning.
   2. Review:
      a. Repair reports.
      b. Special inspection reports.
   3. Verification:
      a. Erection tolerances.
   4. Witness Point:
      a. Grouting/dry-packing of connections and joints.
   5. Hold Point:
      a. Not used.

B. Engage a qualified Testing Agency to perform special inspections.

C. Periodic Special Inspections:
   1. Steel reinforcement placement.
   2. Formwork shape and dimension.
   3. Verify weldability of steel reinforcement other than ASTM A706.
   4. Inspect single-pass fillet welds of maximum 5/16 inch leg length.
   5. Anchors cast in concrete.
   6. Post-installed mechanical anchors.
   7. Verification of use of required design mixture.
   8. Concrete placement, including conveying and depositing.
   9. Curing procedures and maintenance of curing temperature.
   10. Verification of concrete strength before removal of shores and forms from beams and slabs.
   11. Inspect erection of precast structural concrete members.

D. Continuous Special Inspections:
   1. Steel reinforcement welding not covered in scope of Periodic Special Instructions.
   2. Post-installed adhesive anchors.

E. Testing Agency shall report test results promptly and in writing to Contractor and Company.

F. Visually inspect field welds and test according to ASTM E165 or to ASTM E709 and ASTM E1444. High-strength bolted connections are subject to inspections.

G. Repair or remove and replace work where tests and inspections indicate that it does not comply with specified requirements.

H. Perform additional testing and inspecting to determine compliance of replaced or additional work with specified requirements.

I. Prepare test and inspection reports.

END OF SECTION 034100

SECTION 316300 – BORED PILES

PART 1 - GENERAL

1.1 SUMMARY

A. Section includes:
   1. Bored piles forming rock socket for soldier-pile-and-lagging walls.
   2. Dry-installed or support fluid displacement-installed bored piles at Contractor's choice to provide temporary support for construction equipment and reduce surcharge loads on excavation support systems.

B. Related Requirements:
   1. Section 033000 “Cast-In-Place Concrete” for steel reinforcement requirements.
   2. Section 033100 “Structural Concrete Materials” for concrete mix designs.
   3. Section 051200 “Structural Steel Framing” for soldier pile steel requirements.
   4. Section 310913 “Geotechnical Instrumentation and Monitoring” for instrumentation and monitoring requirements.
   5. Section 315000 “Excavation Support and Protection” for general requirements related to use of bored piles as part of excavation support systems.

1.2 DEFINITIONS

A. Bored Pile: A concreted cast-in-place pile (drilled shaft) formed by removing material using non-vibratory and non-displacement methods to create a cased or open, cylindrical hole in the ground which is subsequently filled with concrete and reinforcing.

B. CIP: Cast-in-place.

C. Design Load: The working load permitted on a pile.

D. Ultimate Load: The design load multiplied by the required design safety factor.

1.3 REFERENCES

A. American Association of State Highway and Transportation Officials (AASHTO):
   1. AASHTO R81-17 Standard Practice for Static Segregation of Hardened Self-Consolidating Concrete (SCC) Cylinders.

B. ASTM International (ASTM):
   1. ASTM A36/A36M Standard Specification for Carbon Structural Steel.
   2. ASTM A252/A252M Standard Specification for Welded and Seamless Steel Pipe Piles.
   3. ASTM A283/A283M Standard Specification for Low and Intermediate Tensile Strength Carbon Steel Plates.

4. ASTM A706/A706M Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement.
5. ASTM A929/A929M Standard Specification for Steel Sheet, Metallic-Coated by the Hot-Dip Process for Corrugated Steel Pipe.
6. ASTM C31/C31M Standard Practice for Making and Curing Concrete Test Specimens in the Field.
7. ASTM C39/C39M Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.
8. ASTM C94/C94M Standard Specification for Ready-Mixed Concrete.
9. ASTM C109/C109M Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens).
10. ASTM C143/C143M Standard Test Method for Slump of Hydraulic-Cement Concrete.
11. ASTM C172/C172M Standard Practice for Sampling Freshly Mixed Concrete.
12. ASTM C232/C232M Standard Test Method for Bleeding of Concrete.
13. ASTM C1064/C1064M Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete.
14. ASTM C1077 Standard Practice for Agencies Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Testing Agency Evaluation.
15. ASTM C1611/C1611M Standard Test Method for Slump Flow of Self-Consolidating Concrete.
16. ASTM D3740 Standard Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction.
17. ASTM E329 Standard Specification for Agencies Engaged in Construction Inspection, Testing, or Special Inspection.

C. American Concrete Institute (ACI):
   1. ACI 301/301M Specification for Structural Concrete.
   2. ACI 336.1 Specification for the Construction of Drilled Piers.

D. American Welding Society (AWS):
   1. AWS D1.1/D1.1M Structural Welding Code – Steel.
   2. AWS D1.4/D1.4M Structural Welding Code – Reinforcing Steel.

E. American Petroleum Institute (API):
   1. API 5CT Specification for Casing and Tubing.

F. Concrete Reinforcing Steel Institute (CRSI):
   1. CRSI Manual of Standard Practice.

G. European Federation of Foundation Contractors / Deep Foundations Institute (EFFC/DFI):
   1. Guide to Tremie Concrete for Deep Foundations. 2nd Ed. 2018.

1.4 PREINSTALLATION MEETINGS

A. Conduct pre-installation meeting at project site, attended at a minimum by representatives from the Company, Designer, Contractor, Bored Pile Subcontractor if applicable, and Quality Assurance Personnel including Special Inspector where applicable.

B. Conduct preinstallation meeting after all submittals required to perform the work have been approved, and at least 48 hours prior to starting a new operation.

C. At a minimum, review the following:
1. Health, safety and environmental hazards.
2. Emergency plans and response protocols.
3. Material Safety Data Sheets (MSDS) sheets.
4. Specifications including Field Quality Control requirements.
5. Approved submittals including QA/QC requirements and Inspection and Test Plan.
6. Reporting requirements.
7. Contractor's preparation.
8. Key personnel involved with the work.
9. Contingency plans.

1.5 ACTION SUBMITTALS

A. Product Data:
1. Manufacturer's information, model, size and type of equipment to be used for installing bored piles with appropriate manufacturer's literature.
2. Submit product data for each type of product to be used, including but not limited to concrete, steel reinforcement, and support fluid.

B. Shop Drawings:
1. Show pile details including but not limited to: nominal pile diameter and length; temporary and permanent casing diameter, length and wall thickness; reinforcement.
2. Show details of reinforcement fabricating, bending, supporting, and placing. This includes but is not limited to details of lifting, placement, splicing, centering devices and tremie pipe access reservations.
3. Show details of steel soldier-pile supporting and placing, including but not limited to details of lifting, placement, splicing, centering devices and tremie pipe access reservations.

C. Design Mixes:
1. Concrete: Submit for each concrete mixture including the results of tests on trial batches as specified herein. Submit alternative design mixtures and trial batch test results when characteristics of materials, project conditions, weather, test results, or other circumstances warrant adjustments. Indicate amounts of mixing water to be withheld for later addition at project site.

D. Work Plan:
1. Provide detailed information on the following:
    a. Proposed construction procedure. Include consecutive steps and the approximate time required for each step, and a manpower and equipment usage schedule.
    b. Proposed equipment, including cranes, drills, augers, core barrels, bailing buckets, final cleaning equipment, support fluid pumps, tremies or concrete pumps, and temporary casing.
    c. Shaft excavation methods, including proposed excavation methods through supporting and caving soil or rock layers, proposed use of temporary or permanent casing, and proposed mitigation measures if artesian conditions are encountered.
    d. Methods to achieve and confirm required plan position and verticality tolerances.

e. Proposed support fluid, including sequence of introduction and exchange and methods to mix, circulate, and de-sand.
f. Methods to clean shaft excavation sides and base.
g. Reinforcement placement, including support and centering methods.
h. Concrete placement, including free fall, tremie, or concrete pumping procedures.
i. Methods to prevent excavation spoils or support fluid from entering waterways, wetlands and floodplains.
j. A fall protection plan conforming to the MIOSHA Construction Safety Standards, including a rescue plan for shafts with a diameter greater than 30 inches that are more than 6 feet deep.
k. Bored pile number designations.
l. Bored pile design load.
m. Bored pile diameter, size and length of permanent steel casing. Casting and cut-off elevations.
n. Type and size of reinforcing steel or soldier-pile.
o. Pile head details.

E. Inspection and Test Plan.

F. Corrective Action Plan:
1. Repair procedures and materials for corrective measures to restore or replace non-conforming bored piles to specified requirements. Non-conforming piles are piles not meeting the design requirements indicated on the Agreement Drawings, approved Contractor-design drawings or as specified herein.
2. Submit prior to carrying out corrective measures.

1.6 INFORMATIONAL SUBMITTALS

A. Qualification Data: Resumes or documentation of experience for the following individuals or companies identified in the Quality Assurance requirements to demonstrate the experience requirements are met:
1. Bored Pile Contractor.
2. Design Engineer.
3. Supervisor.
4. Land Surveyor.
5. Welders.

B. Minutes of preinstallation meeting: Within 48 hours of meeting.

C. Certificates:
1. Welding.
2. Cementitious materials.
3. Admixtures.
4. Steel reinforcement and accessories.
5. Steel soldier piles.

D. Minutes of pre-installation meeting within 48 hours of meeting.

E. Test Reports: For each material below, by a qualified testing agency:

1. Aggregates: Include service record data indicating absence of deleterious expansion of concrete due to alkali aggregate reactivity.
2. Reinforcing Steel / Steel Soldier-Piles: Submit mill test reports properly marked. Include the ultimate strength, yield strength, elongation, and material properties composition.
3. Bored Piles Installation Records: Submit installation records for each bored pile within 24 hours of completion containing as a minimum:
    a. Actual top and bottom elevations. Record casting and cut-off top elevation.
    b. Actual bored pile diameter at top and bottom.
    c. Subsurface conditions encountered, including description of soil materials and top of rock elevation.
    d. Description, location, and dimensions of obstructions.
    e. Final top centerline location and deviations from requirements.
    f. Variation of shaft from plumb.
    g. Shaft excavation method.
    h. Depth of rock socket.
    i. Levelness of bottom and adequacy of cleanout.
    j. Properties of support fluid and support fluid test results at time of support fluid placement and at time of concrete placement.
    k. Ground-water conditions and water-infiltration rate, depth, and pumping.
    l. Description, purpose, length, wall thickness, diameter, tip, and top and bottom elevations of temporary casings. Include anchorage and sealing methods used and condition and weather tightness of splices if any.
    m. Description of soil or water movement, sidewall stability, loss of ground, and means of control.
    n. Date and time of starting and completing excavation, reinforcement placement, and concreting.
    o. Inspection report.
    p. Condition of reinforcing steel / steel soldier-pile and splices, and confirmation of conformance to approved Shop Drawings.
    q. Position of reinforcing steel / steel soldier-pile.
    r. Concrete placing method, including record of delays and tremie pipe log recording continuous depth of tremie pipe, depth of concrete and concrete volume.
    s. Elevation of concrete before, during and after removal of casings.
    t. Locations of construction joints.
    u. Concrete volume.
    v. Concrete testing results (strength testing results to follow initial submittal when available). Report test results in writing within 48 hours of testing. List project identification name and number, date of concrete placement, name of concrete testing and inspecting agency, location of concrete batch in work, design compressive strength at 28 days, concrete mixture proportions and materials, compressive breaking strength, and type of break for both 7- and 28-day tests in reports of compressive-strength tests.
    w. Integrity testing results (to follow initial submittal when available).
    x. Remarks, unusual conditions encountered, and deviations from requirements.

F. Record Drawings: Within 14 days of completion of the pile installation, submit as-built drawings showing the location of the piles including deviation from specified location, diameter, top and bottom elevations and inclination.

1.7 QUALITY ASSURANCE

A. Qualifications:
1. Bored Pile Contractor: An experienced contractor that has specialized in bored pile work with at least 10 years' experience installing similar elements (pile type, size, depth, capacity) in similar ground conditions and similar climate.
2. Design Engineer for Contractor-Designed Piles: Registered Professional Engineer licensed in the State of Michigan. With at least 5 years' experience designing similar elements (pile type, size, depth, capacity) in similar ground conditions and similar climate.
3. Supervisor: Assign an experienced, full-time supervisor who has been in responsible charge of supervising bored pile operations for at least five projects, including at least one completed within the last two years. Ensure supervisor is present at the work site at all times during bored pile operations. Provide written verification of the supervisor's experience.
4. Land Surveyor: Professional Land Surveyor in State of Michigan.
5. Testing Agency: Qualified according to ASTM C1077, ASTM D3740, and ASTM E329 for testing indicated.
6. Welding: Qualified procedures and personnel according to the following:
    a. AWS D1.1/D1.1M, "Structural Welding Code - Steel."
    b. AWS D1.4/D1.4M, "Structural Welding Code - Reinforcing Steel."

1.8 PRECONSTRUCTION TESTING

A. Trial Concrete Mixes:
1. Produce a trial batch of at least 4 cubic yards of any proposed bored pile concrete mix. Conduct and report the following tests:
    a. Slump-flow test in accordance with ASTM C1611.
    b. Visual Stability Index in accordance with ASTM C1611.
    c. Slump flow velocity in accordance with EFFC/DFI Guide to Tremie Concrete for Deep Foundations 2nd Ed.
    d. Workability Retention Test in accordance with EFFC/DFI Guide to Tremie Concrete for Deep Foundations 2nd Ed.
    e. Hardened Visual Stability Index in accordance with AASHTO R81.
    f. Bleeding Test in accordance with ASTM C232.
    g. Compressive-Strength Tests in accordance with ASTM C39.

1.9 DELIVERY, STORAGE, AND HANDLING

A. Store and handle controlled support fluid materials in accordance with manufacturer's instructions.

B. Mix, store, and transport controlled support fluid materials using equipment made for this purpose.

1.10 FIELD CONDITIONS

A. Anticipated geotechnical conditions are presented in the Geotechnical Baseline Report (GBR) and Geotechnical Data Reports (GDRs).

B. Visit the site to review all details of the work and working conditions, to verify dimensions in the field including headroom and interference from adjacent or existing structures, and to advise the Designer of any discrepancy before performing any work.

C. Verify continually during construction that field conditions are as anticipated. Report deviations from anticipated conditions to Designer and Company.

PART 2 - PRODUCTS

2.1 PERFORMANCE REQUIREMENTS

A. Code and Standard: Comply with ACI 336.1 except as modified in this Section.

2.2 MATERIALS

A. Steel Reinforcement:
   1. Comply with the requirements of Section 033000 “Cast-In-Place Concrete”.

B. Steel Beams / Steel Soldier Piles:
   1. Comply with the requirements of Section 051200 “Structural Steel Framing”.

C. Steel Casings:
   1. Steel Pipe Casings: ASTM A283/A283M, Grade C, or ASTM A36/A36M, carbon-steel plate, with joints full-penetration welded according to AWS D1.1/D1.1M.
   2. Corrugated-Steel Pipe Casings: ASTM A929/A929M, steel sheet, zinc coated.
   3. Liners: Comply with ACI 336.1.

D. Concrete Materials:
   1. Comply with the requirements of Section 033000 “Cast-In-Place Concrete” and Section 033100 “Structural Concrete Materials”.

E. Support Fluid:
   1. Pulverized bentonite, pulverized attapulgite or polymers mixed with water to form stable colloidal suspension; complying with ACI 336.1 for density, viscosity, sand content, and pH.

F. Miscellaneous:
   1. Centralizers: Fabricate from plastic, steel or a material which is non-detrimental to the reinforcing steel. Do not use wood.

2.3 REINFORCEMENT FABRICATION

A. Comply with the requirements of Section 033000 “Cast-In-Place Concrete”.

2.4 CONCRETE MIXING

A. Ready-Mixed Concrete: Measure, batch, mix, and deliver concrete according to ASTM C 94, and furnish batch ticket information.

1. When air temperature is between 85 and 90 deg F, reduce mixing and delivery time from 1-1/2 hours to 75 minutes; when air temperature is above 90 deg F, reduce mixing and delivery time to 60 minutes.

2. When air temperature is below 40 deg F or ground is frozen comply with cold-working requirements defined in Section 033100 “Structural Concrete Materials”.

2.5 SOURCE QUALITY CONTROL

A. At a minimum, include the following items in the Inspection and Test Plan:
1. Surveillance:
   a. Concrete batching plant inspection at a minimum of 7 days’ notice.
   b. Steel reinforcement / steel soldier-pile fabrication yard inspection at a minimum of 7 days’ notice.
2. Review:
   a. Welding certificates.
3. Verification:
   a. Concrete design mixes.
   b. Steel soldier pile product data.
4. Witness Point:
   a. Not used.
5. Hold Point:
   a. Not used.

PART 3 - EXECUTION

3.1 PREPARATION

A. Obtain and submit for review and approval all required permits.

B. Protect structures, utilities, sidewalks, pavements, and other facilities from damage caused by settlement, lateral movement, vibration, and other hazards created by bored pile operations.

C. Locate all existing underground facilities and utilities on-site and immediately report conflicts or proposed changes. Do not begin excavation until all conflicts have been resolved.

D. Protect existing Line 5 pipeline as required.

E. Ensure piling work is coordinated with other disciplines or trades.

F. Complete survey work to mark pile location.

3.2 EXCAVATION

A. Prevent surface water from entering excavated shafts. Conduct water to site drainage facilities.

B. Excavate shafts for bored piles to elevations indicated on Agreement Drawings. Remove loose material from bottom of excavation.
   1. Excavate bottom of bored pile to level plane within 1:12 tolerance.
   2. Remove water from shafts excavated in the dry before concreting.
   3. Excavate rock sockets of dimensions indicated.

C. Notify and allow Special Inspector to test and inspect bottom of excavation. If unsuitable bearing stratum is encountered, make adjustments to bored piles as determined by the Designer.
   1. Do not excavate shafts deeper than elevations indicated unless approved by the Designer.

D. Excavate shafts for closely spaced bored piles only after adjacent bored piles are filled with concrete and allowed to set.

E. Support Fluid: If required, stabilize excavation with support fluid maintained a minimum of 60 inches above ground-water level and above unstable soil strata to prevent caving or sloughing of shaft. Maintain support fluid properties before concreting. Excavate and complete concreting of bored pile on same day unless delay in concreting is approved by the Designer. Collect displaced support fluid and dispose of in accordance with Company's Environmental Protection Plan and Permits.

F. Temporary Casings: Install watertight steel casings of sufficient length and thickness to prevent water seepage into shaft; to withstand compressive, displacement, and withdrawal stresses; and to maintain stability of shaft walls.
   1. Remove temporary casings, maintained in plumb position, during concrete placement and before initial set of concrete.

G. Tolerances: Construct bored piles to remain within ACI 336.1 tolerances with the following additional requirements:
   1. For Soldier Piles and Bearing Piles:
      a. Allowable maximum offset from specified plan position at cut-off elevation is 2 inches.
      b. Allowable maximum deviation from plumb is 1%.
   2. If location or out-of-plumb tolerances are exceeded, provide corrective construction. Submit corrective construction proposals to Designer for review before proceeding.

3.3 OBSTRUCTION REMOVAL FROM BORED PILE EXCAVATION

A. When obstructions are encountered, notify the Company promptly.

B. When efforts to advance past an obstruction to the base of the bored pile result in a reduction in the rate of advance and/or change in approved means and methods relative to the approved bored pile work plan, then remove, bypass or break up the obstruction.

3.4 STEEL REINFORCEMENT INSTALLATION

A. Comply with Section 033000 "Cast-In-Place Concrete" for fabricating, placing, and supporting reinforcement.

B. Clean reinforcement of loose rust and mill scale, earth, and other materials that reduce or destroy bond with concrete.

C. Fabricate and install reinforcing cages or core beams symmetrically about axis of shafts in a single unit.

D. Accurately position, support, and secure reinforcement against displacement during concreting. Maintain minimum cover over reinforcement.

E. Use spacers or centering devices that are non-corrosive. Do not use concrete blocks or wood blocks on the sides of the shaft.

F. For reinforcement cages, provide spacers at quarter points around the cage and at intervals no greater than 5 feet along the cage.

G. For soldier beams, provide spacers at the sides of each flange at a minimum spacing of 10 feet along soldier beam.

H. Use templates to set anchor bolts, leveling plates, and other accessories furnished in work of other Sections. Provide blocking and holding devices to maintain required position during final concrete placement. Use centering devices.

I. Provide extended reinforcement as defined on the Agreement Drawings. Protect exposed ends of extended reinforcement, dowels, or anchor bolts from mechanical damage and exposure to weather.

J. Provide temporary steel to maintain shape of reinforcing cage during lifting operations and to facilitate tremie pipe installation as necessary.

3.5 CONCRETE PLACEMENT

A. Place concrete in continuous operation from bottom to top and without segregation immediately after inspection and approval of bore by a qualified Special Inspector Testing Agency.

B. Dry Method: Place concrete to fall vertically down the center of bored pile without striking sides of shaft or steel reinforcement. Use a centering drop chute, at least 3 feet long with the free-fall method.

1. Where concrete cannot be directed down shaft without striking reinforcement, place concrete with chutes, tremies, or pumps.
2. For soldier piles with core beam reinforcement, place concrete in a manner such that it does not strike core beam and is able to rise evenly within the bore.
3. If concrete placement causes the shaft excavation to cave or slough, or if concrete strikes the rebar cage or sidewall, reduce the height of free-fall, the rate of concrete flow into the

excavation, or both. Do not use a shovel or other means to deflect the concrete discharged directly from the truck.

4. If the Designer determines dewatering is impractical, or concrete placement by free-fall method cannot be accomplished, place concrete using a tremie or a concrete pump.
5. For uncased dry holes in soil, it is permissible to place the concrete in free fall up to 30 ft. provided a centering device is used to prevent the falling concrete from hitting the sidewall soil. The 30 ft depth limit may be extended if the responsible field geotechnical engineer provides written approval that the free fall of concrete will not hit the bored shaft wall or displace the rebar cage. Otherwise, use a long down pipe to direct the concrete away from the reinforcement.
6. For fully cased dry holes or dry holes through solid rock, it is permissible to place concrete in free fall to any depth provided a centering device is used that will prevent the falling concrete from hitting the reinforcement.

C. Support Fluid Displacement Method: Place concrete in support fluid-filled shafts by tremie methods or pumping. Control placement operations to ensure that tremie or pump pipe is embedded no less than 10 feet into concrete following initiation of concrete discharge and that flow of concrete is continuous from bottom to top of bored piles.

1. Use tremies with a tube of a length, weight, and diameter to discharge concrete at the shaft base elevation. Do not allow aluminum parts to contact the concrete. Use tremies with an inside diameter of at least 10 inches.
2. Provide tremies with smooth, clean inside and outside surfaces to allow flow of concrete and unimpeded tremie withdrawal during concreting. Use tremies with thick walls to prevent crimping or sharp bends that restrict concrete placement.
3. For concrete placement, use watertight tremies. Do not begin underwater concrete placement until positioning the tremie to the shaft bottom elevation. Use valves, bottom plates, or plugs to initiate concrete discharge within one tremie diameter of the base. Remove plugs from the excavation or use plugs of a Designer-approved material that does not cause defects in the shaft if not removed. Construct the discharge end of the tremie to allow the free radial flow of concrete during placement operations. Immerse the tremie discharge end at least 10 feet in concrete after beginning the concrete flow.
4. Place concrete continuously until shaft completion. Keep the shaft full of concrete and the tremie submerged in placed concrete. Raise the tremie as necessary to maintain the free flow of concrete and casing stability.

D. Pumped Concrete:

1. Pump concrete into wet or dry excavations, using concrete pump pipe with a diameter of at least 4 inches and constructed with watertight joints. Arrange the concrete pump equipment so vibrations do not damage fresh concrete. Arrange pipes carrying concrete from the pump to the pile with minimal bends. Anchor pipes conveying concrete to the bottom of the pile shaft excavation to the steel casing or other stationary objects to prevent the pipe from undulating during initial concrete placement. Do not begin concrete placement until positioning the pump line orifice at the shaft base elevation.
2. Do not use aluminum pipe to convey concrete. Operate the pump to produce a continuous stream of concrete without air pockets. To prevent contamination of concrete placed initially at the bottom of the shaft excavation, seal the outlet end of the pumping pipe with a diaphragm or plug flushed out when the hydrostatic pressure from the column of concrete exceeds that of the water in the pile shaft excavation.
3. Control the initial rate of concrete placement to prevent lift or displacement of the reinforcing steel cage. Use a watertight conveying system, and maintain the outlet end at

least 10 feet below the top of freshly placed concrete. When concrete reaches the top of the bored pile column, remove laitance.

E. Consolidate the top 5 feet of concrete for all piles by mechanical means. Vibrating concrete by applying the vibrator to reinforcing steel is not permitted.

F. When a protective casing is used, withdraw while concrete is being placed and maintain integrity of placed concrete during withdrawal. Keep the bottom of the casing a minimum of 5 feet below the level of concrete (or as required to exclude water and soil intrusion during extraction).

G. Ensure that the reinforcement is not disturbed or exposed to surrounding soil when removing protective casing. Excavation around piles to facilitate extraction of casings is not permitted.

H. Screed concrete at cutoff elevation level and apply scoured, rough finish. Where cutoff elevation is above the ground elevation, form top section above grade and extend shaft to required elevation.

I. Protect concrete work, according to ACI 301, from frost, freezing, or low temperatures that could cause physical damage or reduced strength.

1. Do not use frozen materials or materials containing ice or snow. Do not place concrete on frozen subgrade or on subgrade containing frozen materials.
2. Do not use calcium chloride, salt, or other mineral-containing antifreeze agents or chemical accelerators.

J. If hot-weather conditions exist that would seriously impair quality and strength of concrete, place concrete according to ACI 301 to maintain delivered temperature of concrete at no more than 90 deg F (32 deg C).

1. Place concrete immediately on delivery. Keep exposed concrete surfaces and formed shaft extensions moist by fog sprays, wet burlap, or other effective means for a minimum of seven days.

3.6 DISPOSAL OF SURPLUS AND WASTE MATERIALS

A. Disposal: Remove surplus satisfactory soil and waste material, including unsatisfactory soil, trash, and debris, and legally dispose of it off the Company's property.

3.7 FIELD QUALITY CONTROL

A. At a minimum, include the following items in the Inspection and Test Plan:
1. Surveillance:
   a. Not used.
2. Review:
   a. Bored pile installation records.
3. Verification:
   a. Concrete test results.
   b. Tremie pipe control within specification requirements.
4. Witness Point:
   a. Not used.

5. Hold Point:
    a. Bored pile excavated in accordance with specification requirements.
    b. Reinforcement cage or soldier beam in compliance with specification and approved Shop Drawings.
    c. Reinforcement / steel soldier pile placed into bore in accordance with specification requirements.

B. Special Inspection: Provide access for the Special Inspector to perform independent quality control activities as follows:
1. For Soldier-Piles:
    a. Continuous inspection of drilling operations and maintenance of complete and accurate records for each element.
    b. Continuous inspection and record keeping for each element to verify placement locations and plumbness, confirm element diameters / sizes and lengths, and record concrete volumes.
2. For Cast-in-Place Concrete Elements:
    a. Periodic inspection of reinforcement prior to placement, and verification of placement.
    b. Periodic inspection to verify weldability of reinforcing bars other than ASTM A706.
    c. Periodic inspection of single pass filet welds of maximum size 5/16 inch.
    d. Continuous inspection of all other welds.
    e. Periodic inspection of anchors cast in concrete.
    f. Periodic inspection of mechanical anchors.
    g. Periodic inspection to verify use of required design mix.
    h. Continuous inspection to fabricate specimens for strength tests, perform slump and air content tests, and determine the temperature of the concrete.
    i. Continuous inspection of concrete and shotcrete for proper application techniques.
    j. Periodic inspection to verify maintenance of specified curing temperature and techniques.
    k. Periodic inspection to verify in-situ concrete strength prior to removal of shores and forms from beams and structural slabs.
    l. Periodic inspection of formwork for shape, location and dimensions of the concrete member being formed.
3. For Structural Steel Elements:
    a. Periodic inspection of welded or bolted end connections.

C. Bored Pile Tests and Inspections: For each bored pile, before concrete placement.
1. Soil and Rock Testing: Bottom elevations, bearing capacities, and lengths of bored piles indicated have been estimated from available soil data. Actual elevations and bored pile lengths and bearing capacities are determined by testing and inspecting agency. Final evaluations and approval of data are determined by the Designer.
2. Surveying Plan Position:
    a. Survey center of bore or temporary casing prior to concrete placement.
    b. Survey center of installed element at cutoff level.
3. Measuring Verticality:
    a. Determine shape and verticality pile shaft by mechanical calipers or ultra-sonic calipers. Ultra-sonic calipers may be Kelly bar mounted.
4. Assessing Shaft and Base Condition:
    a. For short piles constructed using Dry Method, inspect base visually from ground surface where possible. Have available at all times a suitably powerful light that can be lowered down shaft and that is capable of illuminating sides and base of shaft to

aid inspection. If satisfactory visual inspection, as judged by Contractor's quality personnel, the Company, and the Designer, is not possible then inspect base visually using downhole camera system capable of producing and recording high resolution color video of entirety of shaft and base.

b. For long piles constructed using Dry Method, inspect base visually using downhole camera system capable of producing and recording high resolution color video of entirety of shaft and base.

D. An excavation, concrete, or a bored pile will be considered defective if it does not pass tests and inspections.

E. Unacceptable Piles: Unacceptable piles are piles that are rejected by the Company because of damage, failure to advance through obstructions, mis-location, mis-alignment, failure to meet load test acceptance criteria, failure to install the pile using the approved equipment and procedures, or failure to install the pile to the proper bearing stratum. To mitigate and/or to remedy unaccepted piles, the Contractor may be required to provide additional piles or supplement piles to meet specified requirements.

F. Concrete Tests and Inspections:
1. Sample in accordance with ASTM C172.
    a. Slump-flow test in accordance with ASTM C1611.
    b. Visual Stability Index in accordance with ASTM C1611.
    c. Slump flow velocity in accordance with EFFC/DFI Guide to Tremie Concrete for Deep Foundations 2nd Ed.
    d. Workability Retention Test in accordance with EFFC/DFI Guide to Tremie Concrete for Deep Foundations 2nd Ed.
    e. Hardened Visual Stability Index in accordance with AASHTO R81.
    f. Bleeding Test in accordance with ASTM C232.
2. Slump-flow in accordance with ASTM C1611: one test at point of placement for each compressive-strength test but no fewer than one test for each concrete load.
3. Visual Stability Index in accordance with ASTM C1611: one test at point of placement for each compressive-strength test but no fewer than one test for each concrete load.
4. Slump flow velocity in accordance with EFFC/DFI Guide to Tremie Concrete for Deep Foundations 2nd Ed: At least once per week of bored pile installation.
5. In the event that concrete stability or workability issues are observed, including excessive bleed, complete the following tests once per pile and provide results on a daily basis. Discontinue testing only once issues are resolved:
    a. Workability Retention Test in accordance with EFFC/DFI Guide to Tremie Concrete for Deep Foundations 2nd Ed.
    b. Hardened Visual Stability Index in accordance with AASHTO R81.
    c. Bleeding Test in accordance with ASTM C232.
6. Concrete Temperature in accordance with ASTM C1064 one test hourly when air temperature is 40 deg F (4.4 deg C) and below and 80 deg F (27 deg C) and above, and one test for each set of compressive-strength specimens.
7. Compression Test Specimens in accordance with ASTM C31: one set of four standard cylinders for each compressive-strength test unless otherwise indicated. Mold and store cylinders for laboratory-cured test specimens unless field-cured test specimens are required.
8. Compressive-Strength Tests in accordance with ASTM C39: one set for each bored pile but not more than one set for each truck load. Test one specimen at seven days, test two specimens at 28 days, and retain one specimen in reserve for later testing if required.

9. If frequency of testing provides fewer than five strength tests for a given class of concrete, conduct tests from at least five randomly selected batches or from each batch if fewer than five are used.
10. If strength of field-cured cylinders is less than 85 percent of companion laboratory-cured cylinders, evaluate operations and provide corrective procedures for protecting and curing in-place concrete.
11. Strength of each concrete mixture is satisfactory if every average of any three consecutive compressive-strength tests equals or exceeds specified compressive strength and no compressive-strength test value falls below specified compressive strength by more than 500 psi.
12. Nondestructive Testing: Impact hammer, sonoscope, or other nondestructive device may be permitted by Designer but not be used as sole basis for approval or rejection of concrete.
13. Additional Tests: Testing and inspecting agency to make additional tests of concrete if test results indicate that slump, compressive strengths, or other requirements have not been met, as directed by the Company.
14. Continuous coring of bored piles may be required, if temporary casings have not been withdrawn within specified time limits, if observations of placement operations indicate deficient concrete quality, presence of voids, segregation, or other possible defects, or if integrity testing identifies potential defects.
15. Perform additional testing and inspecting, to determine compliance of replaced or additional work with specified requirements.
16. Correct deficiencies in the work that test reports and inspections indicate do not comply with the Agreement and Exhibits.

G. Integrity Testing:
   1. Not required on rock sockets for soldier-pile walls.
   2. For integrity testing requirements for bored piles installed to provide temporary support for construction equipment see requirements on relevant Agreement Drawings or in Contractor-design documentation.

H. Load Testing:
   1. Not required on bored piles for soldier-pile walls.
   2. For load testing requirements for bored piles installed to provide temporary support for construction equipment see requirements on relevant Agreement Drawings or approved Contractor-design drawings.

END OF SECTION 316300

SECTION 317416 – PRECAST CONCRETE TUNNEL LINING

PART 1 - GENERAL

1.1 SUMMARY

A. Section includes the requirements for manufacturing, handling, transporting and installing gasketed precast concrete tunnel lining (PCTL) segments. This includes necessary labor, materials, tools, and equipment to obtain a tunnel meeting the water infiltration requirements, capable of erection within the Tunnel Boring Machine, resisting ground and groundwater loads and loads imposed during manufacture, handling, transportation, installation and operation.

B. Related Requirements:
   1. Section 310179 “Sealing Leaks” for furnishing equipment, labor, and grouting material and installing grout as required to seal leaks to prevent water ingress into the Straits Tunnel. All other repair requirements for the PCTL are in this section.
   2. Section 317119 “Excavation by Tunnel Boring Machine” for completion of the bored tunnel with the use of a Pressurized Face Tunnel Boring Machine (TBM), including installing the permanent tunnel lining consisting of gasketed precast concrete segments.

1.2 DEFINITIONS

A. Appurtenances: Manufactured products that are cast into or fixed to the segments, and include gaskets, bolts, dowels, alignment rods, grout sockets and packing.

B. Bearing Offset: The difference in alignment between two adjacent segments. This is a measurement of the step between segments and provides a measure of the reduction of the contact surface between the adjacent gaskets.

C. Cementitious Materials: Portland cement in combination with one or more of the following additions: fly ash, slag cement, other pozzolans, and silica fume; or equivalent hydraulic blended cements.

D. Circumferential Joint: The segment joint face between adjacent rings.

E. Clock Position: Term used to describe each of the 16 locations of the joint connection system on the circumferential joint.

F. EPDM: ‘Ethylene-Propylene-Diene-Monomer’ elastomeric material.

G. Gasket: A water sealing system consisting of a continuous, deformable, elastomeric gasket (typically EDPM or NBR) attached to each segment mating face to provide permanent water tightness for the erected tunnel lining.

H. Gasket Differential Gap: The difference between complete gasket compression (zero gap) and actual gasket compression. This is the measurement of incomplete closure between two joint faces.

I. Ground Granulated Blast Furnace Slag (GGBFS): Supplementary cementitious material produced from slag byproduct of iron production using blast furnaces.

J. Guide Rods: A plastic dowel placed on the radial joint and used to reduce bearing offset.

K. Inserts: Appurtenances that are cast in the segments.

L. Joint Connection System: Assembly of bolt or dowel used to mechanically link segments across joint faces and compress the gasket. Includes an insert integrally cast with the segments and fully embedded in concrete.

M. Key Restraint System: Set of engineering components designed to be bolted to the key segment and the previous ring to provide restraint against key movement.

N. NBR: 'Nitrile Butadiene Rubber' elastomeric material.

O. Packing: Sheet material attached to the circumferential joint, to distribute compressive stresses across the joints.

P. Precast Concrete Tunnel Lining (PCTL): Precast concrete segments with steel rebar and steel fiber reinforcement, stirrups, ties, etc. and appurtenances that are erected and fixed together to produce a series of complete rings.

Q. Radial Joint: The segment joint face between adjacent segments in the same ring.

R. Stripping: The removal of a cast concrete segment from the mold after initial curing at a predetermined minimum concrete compressive strength.

S. Type A Segments: Standard segments used for most of the alignment.

T. Type B Segments: Segments with higher concrete strength and higher reinforcement percentages used in the most heavily loaded sections of the alignment.

U. W/C Ratio: The ratio by weight of water to cementitious materials.

V. Working Pressure: The expected maximum external hydrostatic pressure on the structure, 17.2 bar.

1.3 REFERENCES

A. American Association of State Highway Transportation Officials (AASHTO):
   1. AASHTO T21 Standard Method of Test for Organic Impurities in Fine Aggregates for Concrete.
   2. AASHTO T71 Standard Method of Test for Effect of Organic Impurities in Fine Aggregate on Strength of Mortar.

B. American Concrete Institute (ACI):
1. ACI 117 Standard Specifications for Tolerances for Concrete Construction and Materials.
2. ACI 211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete.
3. ACI 224.1R Causes, Evaluation, and Repair of Cracks in Concrete Structures.
4. ACI 301 Specifications for Structural Concrete.
5. ACI 304R Guide for Measuring, Mixing, Transporting, and Placing Concrete.
6. ACI 304.2R Guide to Placing Concrete by Pumping Methods.
7. ACI 305.1, Specification for Hot Weather Concreting.
8. ACI 305R Guide to Hot Weather Concreting.
9. ACI 306.1 Standard Specification for Cold Weather Concreting.
10. ACI 306R Guide to Cold Weather Concreting.
11. ACI 308R Guide to External Curing of Concrete.
12. ACI 309R Guide for Consolidation of Concrete.
13. ACI 517.2R Accelerated Curing of Concrete at Atmospheric Pressure.
14. ACI 533.2R Guide on General Design and Construction Aspects of Precast Concrete Tunnel Segments.

C. ASTM International (ASTM):
1. ASTM A706/A706M Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement.
2. ASTM A820/A820M Standard Specification for Steel Fibers for Fiber-Reinforced Concrete.
3. ASTM A1064/A1064M Standard Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete.
4. ASTM C31/C31M Standard Practice for Making and Curing Concrete Test Specimens in the Field.
5. ASTM C33/C33M Standard Specification for Concrete Aggregates.
6. ASTM C39/C39M Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.
7. ASTM C40/C40M Standard Test Method for Organic Impurities in Fine Aggregates for Concrete.
8. ASTM C42/C42M Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete.
9. ASTM C94/C94M Standard Specification for Ready-Mixed Concrete.
10. ASTM C136/C136M Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.
11. ASTM C138/C138M Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete.
12. ASTM C143/C143M Standard Test Method for Slump of Hydraulic-Cement Concrete.
13. ASTM C150/C150M Standard Specification for Portland cement.
14. ASTM C157/C157M: Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete.
15. ASTM C171 Standard Specification for Sheet Materials for Curing Concrete.
16. ASTM C172/C172M Standard Practice for Sampling Freshly Mixed Concrete.
17. ASTM C231/C231M Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method.
18. ASTM C260/C260M Standard Specification for Air-entraining Admixtures for Concrete.
19. ASTM C309 Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete.

20. ASTM C457/C457M Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete.
21. ASTM C494/C494M Standard Specification for Chemical Admixtures for Concrete.
22. ASTM C595/C595M Standard Specification for Blended Hydraulic Cements.
23. ASTM C618 Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.
24. ASTM C666/C666M Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing.
25. ASTM C856/C856M Standard Practice for Petrographic Examination of Hardened Concrete.
26. ASTM C881/C881M Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete.
27. ASTM C928/C928M Standard Specification for Packaged, Dry, Rapid-Hardening Cementitious Materials for Concrete Repairs.
28. ASTM C989/C989M Standard Specification for Slag Cement for Use in Concrete and Mortars.
29. ASTM C1064/C1064M Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete.
30. ASTM C1074 Standard Practice for Estimating Concrete Strength by the Maturity Method.
31. ASTM C1077 Standard Practice for Agencies Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Testing Agency Evaluation.
32. ASTM C1116/C1116M Standard Specification for Fiber-Reinforced Concrete.
33. ASTM C1152/C1152M Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete.
34. ASTM C1202 Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration.
35. ASTM C1240 Standard Specification for Silica Fume Used in Cementitious Mixtures.
36. ASTM C1260 Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method).
37. ASTM C1315 Standard Specification for Liquid Membrane-Forming Compounds Having Special Properties for Curing and Sealing Concrete.
38. ASTM C1567 Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method).
39. ASTM C1602/C1602M Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete.
40. ASTM C1697 Standard Specification for Blended Supplementary Cementitious Materials.
41. ASTM C1778 Standard Guide for Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete.
42. ASTM D395 Standard Test Methods for Rubber Property—Compression Set.
43. ASTM D412 Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers – Tension.
44. ASTM D471 Standard Test Method for Rubber Property—Effect of Liquids.
45. ASTM D573 Standard Test Method for Rubber—Deterioration in an Air Oven.
46. ASTM D813 Standard Test Method for Rubber Deterioration – Crack Growth.
47. ASTM D1149 Standard Test Methods for Rubber Deterioration - Cracking in an Ozone Controlled Environment.
48. ASTM D2240 Standard Test Method for Rubber Property – Durometer Hardness.
49. ASTM F3125/F3125M Standard Specification for High Strength Structural Bolts and Assemblies, Steel and Alloy Steel, Heat Treated, Inch Dimensions 120 ksi and 150 ksi

Minimum Tensile Strength, and Metric Dimensions 830 MPa and 1040 MPa Minimum Tensile Strength.

50. ASTM WK73384 New Test Method for Evaluating the Tensile Performance of Fiber-Reinforced Concrete Using Cylindrical Specimens with Double-Punch Loading.

D. American Welding Society (AWS):
   1. AWS D1.4 – Structural Welding Code – Reinforcing Steel.

E. Canadian Standards Association (CSA):
   1. A23.2 Standard Test Method for Determination of Steel or Synthetic Fibre Content in Plastic Concrete.

F. Euronorm (British Standards versions):
   1. BS EN 206 Concrete — Specification, performance, production and conformity.
   2. BS EN 1744 Tests for Chemical Properties of Aggregates.
   3. BS EN 14651 including A1: Test Method for Metallic Fibre Concrete – Measuring the flexural tensile strength (limit of proportionality (LOP), residual).

G. German Institute for Standardization (DIN):
   1. DIN ISO 3302-01 Rubber- Tolerances for Products.

H. International Federation for Structural Concrete - Fédération internationale du béton (*fib*):
   1. fib Bulletin No. 34, "Model Code for Service Life Design," Model Code prepared by fib Task Group 5.6, 2006.

I. Michigan Department of Transportation (MDOT) Manual for the Michigan Test Methods (MTM):
   1. MTM 102 Michigan Test Method for Abrasion Resistance of Aggregate by the Los Angeles Machine.
   2. MTM 108 Michigan Test Method for Materials Finer than No. 75 µm (No. 200) Sieve in Mineral Aggregates by Washing.
   3. MTM 109 Michigan Test Method for Sieve Analysis of Fine, Dense Graded, Open Graded and Coarse Aggregates in the Field.
   4. MTM 110 Michigan Test Method for Determining Deleterious and Objectionable Particles in Aggregates.
   5. MTM 115 Michigan Test Method for Testing Concrete for Durability by Rapid Freezing in Air and Thawing in Water.
   6. MTM 117 Michigan Test Method for Determining Percentage of Crushed Particles in Aggregates.

J. Nord Test:
   1. NT BUILD 492 Concrete, mortar and cement-based repair materials: Chloride migration coefficient from non-steady-state migration experiments.

K. NPCA Quality Control Manual for Precast and Prestressed Concrete Plants

L. Precast/Prestressed Concrete Institute (PCI):
   1. PCI MNL-116 Manual for Quality Control for Plants and Production of Structural Precast Concrete Products.

M. Studiengesellschaft für Tunnel und Verkehrsanlagen e. V. (STUVA):

1. 54 Forschung + Praxis: Recommendation for Gasket Frames in Segmental Tunnel Linings.

N. US Army Corp of Engineers:
1. CRD-C 48 Standard Test Method For Water Permeability Of Concrete.

1.4 PREPRODUCTION MEETINGS

A. Conduct a preproduction meeting after all submittals required to perform the work have been approved, and at least two weeks prior to start of production casting.

B. The preproduction meeting is to be attended by representatives from the PCTL manufacturer, the Company, Designer and Contractor.

C. Review the following items in the preproduction meeting:
1. Health, safety and environmental hazards.
2. Emergency plans and response protocols.
3. Material Safety Data Sheets (MSDS) sheets.
4. Specifications and PCTL manufacturer's submittals.
5. Work plans and construction methods.
6. Schedule.
7. PCTL manufacturer's Quality Control (QC) Plan.
8. Results from source and field QC (concrete, mold and segment geometry, trial ring, etc.).
9. Segment Tracking Database System.
10. Key personnel involved with the work.

1.5 ACTION SUBMITTALS

A. Product Data:
1. Concrete mix designs.
2. Cement, fly ash, GGBFS and silica fume.
3. Aggregates.
4. Data sheets for admixtures (such as water-reducing admixtures).
5. Data sheets for form release agents.
6. Data sheets for curing materials.
7. Data sheets for steel fibers, polypropylene fibers, and reinforcement supports.
8. Drawings and data sheets for all inserts including the components of joint connection system describing pullout capacity and material properties of the assemblies, including:
    a. Pullout capacity in embedded condition, including a pullout force vs deflection plot and yield capacity.
    b. Minimum shear capacity on guide rods, including a shear force vs deflection plot.
    c. Durability reports for relevant appurtenances demonstrating performance under specified conditions.
9. Drawings and data sheets for the gaskets, including:
    a. Required gasket groove dimensions, to allow the Agreement Drawings to be updated as needed.
    b. Material specifications.
    c. Gasket manufacturer's QC plan ensuring consistency of gasket material, dimensions, configurations and installation.
    d. Gasket adhesive.

e. Drawings with details of each gasket frame with color coding or other identification system, details of special joint angles and other construction details.
f. Gasket manufacturer's recommendations / QC Manual, including:
   1) Storage procedures.
   2) Proper handling procedures.
   3) Gasket frame installation.
   4) Repair instructions.
   5) Special instructions for corners and intersections.
   6) Installation equipment if any.
   7) Health and safety data / MSDS sheets.
g. Gasket manufacturer's certification that intrados gasket material is resistant to hydrocarbon products.
h. Test data, for each gasket profile:
   1) Load deflection force graph for regular section and corner section.
   2) Water tightness graph detailing gasket differential gap and bearing offset variables based on testing with the actual groove configuration to be used on the project.
   3) Long term stress relaxation curve with extrapolation for 100-year duration.
   4) Restorative capacity.

10. Compression versus displacement curves for compression packing under loads up to the equivalent of those from maximum TBM thrust loads for a minimum sample size of 3inch x 3inch.
11. Drawings and data sheets for segment lifting devices and other accessories needed.
12. Data sheets for the foam strip.

B. Shop Drawings:
1. Complete details of formwork and reinforcing for each type of segment, reinforcement spacers and chairs, mechanical joint connection systems, joint stress relief grooves, gasket grooves, gaskets, appurtenances, alignment indicator markings, segment identification and accessories necessary for manufacturing and transportation.

C. Samples:
1. Gasket: Three linear feet and one corner assemblies for both acute and obtuse angles, for each gasket type.
2. Joint Connection System: Two of each set.
3. Compression Packing: Two foot length.
4. Reinforcement Spacers and Chairs: Three each.
5. Grout Ports, including grout plug and back flow preventer: Two of each.
6. Other Inserts: Two of each.
7. Foam Strip: Two foot length.

D. Concrete Product Data, Design Mixtures and Prequalification Mix Development Reports.

E. Work Plan:
1. Provide a Detailed Work Plan 90 days prior to the start of segment production including drawings, procedures, QC plan based on PCI MNL-116 or NPCA Quality Control Manual for Precast and Prestressed Concrete Plants, and description of manufacturing, casting, curing, stripping, handling, transporting, storing, fixing of gaskets, and packing. Information is to include but not be limited to:
   a. Location and layout of facilities for casting, curing and storing segments.
   b. Segment markings and Universal Product Code (UPC) barcode system to be used.

c. Production schedule for segment manufacture.
d. Proposed concrete batching, delivery, placing, finishing and curing methods, and equipment information.
e. Proposed protection procedures for cold and hot weather concreting.
f. Detailed description of procedures for manufacturing, casting, curing, handling, transporting, storing, erecting and repairing segments.
g. Details of tolerance measurement system, including equipment details and accuracy.
h. Procedures for automated electro-resistance welding to fabricate reinforcement, mesh or cages including the QC process used and frequency of weld testing.
i. Procedures for manual welding in accordance with AWS D1.4, including the QC process used and frequency of weld shear testing.
j. Methods to verify concrete cure and strength results from cylinder tests performed in accordance with the requirements of this Section.
k. Methods to verify that the design strength of the segments has been attained prior to stripping, handling, stacking, and use on-site.
l. Modifications to curing procedures if weekly concrete testing demonstrates insufficient minimum stripping strength.
m. Curing process for segment casting to 28 days after casting, including the following:
    1) Detailed work plan for the curing and protection once cast of all precast concrete segments using moist curing, curing compounds or low-pressure steam curing, or a combination of these systems in accordance with ACI 308R.
    2) Measures to control shrinkage and temperature cracking of segments.
    3) Methods to protect segments from direct sunlight and weather if stored outside.
    4) Methods to verify concrete cure and strength results from cylinder tests performed in accordance with the requirements of this Section.
n. Segment repair and rejection criteria and procedures at the factory, in the stockyard and after delivery to site.

F. Minutes of preconstruction meeting, including closure of all action items.

G. If software is proposed to model a virtual ring based on the 3-dimensional laser tracker measurements to replace physical trial rings, submit a report demonstrating the accuracy of the software based on the initial trial ring assembly.

H. Notifications:
1. Notice of start of assembly of demonstration ring.

1.6 INFORMATIONAL SUBMITTALS

A. Qualification Data:
1. For PCTL Manufacturer: Resume for Plant Manager, NPCA/PCI certification and list of comparable tunnel projects and names of clients where manufacturer's segments have been used.
2. For Segment Mold Manufacturer: List of comparable tunnel projects and names of clients where manufacturer's segment molds have been used.
3. For Gasket Manufacturer: List of comparable tunnel projects and names of clients where manufacturer's gaskets have been used.

4. For Independent Testing Agency or in-house testing laboratory: PCI/ACI/ASTM qualifications / certifications for technicians and calibrated testing equipment.

B. Certificates:
1. Fiber reinforcement, for each lot or load, furnish test reports or certificates of compliance indicating the results of testing and certifying that the grades, physical and chemical properties of the fibers are in conformance with applicable ASTM Specifications.
2. AWS D1.4 welding certificates of operators to assemble ladders and bar reinforcement into rebar cages, if manual welds are utilized.
3. Gasket manufacturer's certification of review of the drawings and specifications as provided by the mold manufacturer and confirmation that their gasket(s) will perform as intended considering the groove dimensions, bearing offset, differential gap and adjacent dimensions.
4. Gasket manufacturer's certification of review of the proposed concrete curing materials and confirmation that their gasket will perform as intended.
5. Cementitious materials.
6. Admixtures.
7. Aggregates: Grading, durability and service record data indicating absence of deleterious expansion of concrete due to alkali aggregate reactivity dated less than one year from start of project.
8. Form materials and form-release agents.
9. Steel reinforcement and accessories.
10. Curing compounds.
11. Repair materials.

C. Test Reports: For the following, from a testing laboratory:
1. Test program prior to production of segments to establish curing process for specified strength.
   a. Test data including temperature gradient measurements from trial segments to verify that steam and 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.
2. Data to show that the proposed curing process will result in uncracked segments with the strength required.
3. Test data proving that the welding procedures will develop the full strength of the connected reinforcement bars where required on the Agreement Drawings.

D. Shop Drawings: Not used.

E. Field QC reports for all required tests, checks and inspections.

F. Minutes of pre-construction conference.

G. Results of dimensional checks on molds, segments and trial ring assemblies.

H. Production concrete test results. Provide raw output data from testing apparatus in comma separated value (csv) format and/or agreed alternative format within Segment Tracking Database, linked to the segments cast from the concrete batch that was tested.

I. Monthly report from Independent Testing Agency on independent testing performed.

J. Segment Tracking Database:
1. Provide access to the Segment Tracking Database to the Company and the Designer, including through an interface and allowing continuous, uninterrupted and real-time read access to the live database for external systems. If proprietary format is used, allow for using a standard format such as csv exports. Provide current data identifier for the database.
2. On completion of the project, provide a copy of the complete database including operational system and the interface for a format acceptable to the Company.

1.7 QUALITY ASSURANCE

A. Qualifications:
1. PCTL Manufacturer Qualifications:
   a. The PCTL manufacturer shall be a company regularly engaged in the manufacture and fabrication of bolted, gasketed precast concrete tunnel lining segments of similar dimensions and tolerances to those specified, and who has provided precast concrete tunnel lining segments in the last five years for at least three large projects comparable to this project in size and type.
   b. The PCTL manufacturer shall have five years of experience in the manufacture of reinforcement cages and the use of steel fiber reinforced concrete for precast segmental linings for at least three large projects comparable to the work of this project in size and type.
   c. The facility and welders used for welding reinforcing bar cages, with the exception of welding as agreed with the Designer, shall be qualified in accordance with AWS D1.4.
   d. The manufacturing shall be under the supervision the PCTL manufacturer's Plant Manager, who shall be fully qualified and experienced in the manufacture of bolted, gasketed precast concrete tunnel lining segments of similar dimensions and tolerances and shall have a minimum of ten years of experience on similar projects.
   e. The PCTL manufacturer shall provide training of their personnel for the manufacture of the segmental lining to cover the following:
      1) With the mold manufacturer to ensure proper usage of the molds and required tolerance checks.
      2) With the reinforcement manufacturer to ensure proper fabrication of the reinforcement cages and required clearance checks prior to casting.
   f. The PCTL manufacturer shall be National Precast Concrete Association (NPCA) and/or Precast/Prestressed Concrete Institute (PCI) Group C certified using the NPCA Quality Control Manual for Precast and Prestressed Concrete Plants, or have a QC program complying with PCI MNL-116.
2. Segment Mold Manufacturer Qualifications:
   a. The mold manufacturer shall have 5 years of experience in the manufacture of molds for precast concrete segmental tunnel linings of similar dimensions and tolerances as those required by this specification.
3. Gasket Manufacturer Qualifications:
   a. The gasket manufacturer shall have 5 years of experience in the manufacture of gaskets for mechanically connected precast concrete segmental tunnel linings of similar dimensions and tolerances as those required by this specification.
4. Testing Laboratory Qualifications:
   a. The Independent Testing Agency, other testing laboratories, and the PCTL manufacturer's in-house testing laboratory, if used, shall have appropriately certified PCI/ACI/ASTM technicians and calibrated equipment.

B. Provide access to the segment manufacturers premises to allow the Company to review the quality of manufacturing. Provide all necessary assistance to the Company on each visit.

1.8 PRECONSTRUCTION TESTING

A. Provide test samples as shown on the Agreement Drawings using the approved design mix for preconstruction testing 9 months prior to the start of production casting, as follows:
   1. Grout Socket Pullout and Watertightness Tests: Six samples with the grout socket cast into a concrete block representing actual dimensions, concrete mix and reinforcement in the segment.
   2. Joint Connections Systems: Provide the following test samples:
      a. Three sets of two separate concrete blocks to test the bolted joint connection system in tension, including the insert embedded in one block, the bolt pocket formed in the other block and the proposed bolt, with the blocks representing the actual dimensions, concrete mix and reinforcement in a Type A segment.
      b. Six sets of two separate concrete block pairs to test the dowelled joint connection system in shear and tension, with the blocks representing the actual dimensions, concrete mix and reinforcement in a Type A segment, and one of the proposed dowels with each set.
      c. A key segment and one other segment in the ring for a key pull out capacity test, to determine the minimum (yield) pullout capacity of the combined key restraint components. Provide one pair of segments (key plus one other segment) for both Type A and Type B rings.
   3. Fire Testing: Provide four rectangular samples of each proposed concrete mix and reinforcement, with different dosages of polypropylene fibers as shown on the Agreement Drawings.
   4. Joint Performance: Provide the following test samples:
      a. Three sets of two separate concrete blocks representing both Type A and Type B segments (total of 2 x 3 x 2 = 12 blocks) to test the joints under load. One face of the blocks shall accurately represent the segment joint face.
      b. Three sets of two separate concrete blocks representing both Type A and Type B segments (total of 2 x 3 x 2 = 12 blocks) to test the gaskets/segment interface under load. Two faces of the blocks shall accurately represent the segment joint face.
      c. One Type A and one Type B segment, for testing under thrust jack loading.

B. Gaskets:
   1. Groove Loads: Demonstrate through a combination of engineering analysis and laboratory testing in accordance with STUVA 54 on a minimum of three samples of each gasket type by a qualified independent laboratory that the gasket will not exert a load deflection force greater than specified in this Section, for each of the following cases:
      a. Load-displacement behavior of the gasket profile (straight section).
      b. Load-displacement behavior of the gasket corner.
   2. Test gaskets water tightness as follows:
      a. Simulate a range of conditions of bearing offset and gasket differential gap using a test rig, including the worst combination to be encountered in the completed structure. Test for a bearing offset of 0.4 inches and gasket differential gap of 0.2 inches at a minimum.
      b. Use a T-joint test rig for the testing device in accordance with STUVA 54, with steel plates for gasket mounting fixtures machined to match the PCTL gasket profile

dimensions. Test for a bearing offset of 0.4 inches and gasket differential gap of 0.2 inches at a minimum.

c. In each test increase the water pressure in increments of 1 bar and hold at each value for 5 minutes.
d. Gaskets are not permitted to be glued in.
e. Ensure that the flat corners are seated correctly.
f. The final test pressure shall be at least double the maximum working pressure. Maintain this pressure for 24 hours during which no leakage shall occur at the gasketed faces.
g. Perform tests at normal ambient temperature.

3. Demonstrate the stress relaxation through laboratory testing in accordance with STUVA 54 on a minimum of three samples by a qualified independent laboratory.
4. Demonstrate the restorative capacity through laboratory testing in accordance with STUVA 54 on a minimum of three samples by a qualified independent laboratory.

1.9 DELIVERY, STORAGE, AND HANDLING

A. Steel Reinforcement: Deliver, store, and handle steel reinforcement to prevent bending and damage.

B. Stack segments on a level base, supported as shown on the Agreement Drawings at approximately quarter points with wood blocking, sleepers, or similar to avoid damage. When stacked, position segments in a safe and stable manner and with blocking in vertical alignment with a horizontal deviation of no more than shown on the Agreement Drawings.

C. Store segments with joint compression packing and gaskets attached under conditions that will not be detrimental to either. In particular, confirm and comply with the exposure conditions for the chemically resistant intrados gasket, which is likely to be sensitive to sunlight. Replace gaskets and joint compression packing that have been damaged or deteriorated through exposure or have remained on segments for an extended period, as determined by the Designer.

D. Provide lifting devices that minimizes handling stresses on the segments by either lifting segments at the quarter points or providing continuous lifting force over at least 50% of the segment length.

E. Do not allow chains, wire ropes, etc. to bear against segment surface while lifting.

F. Do not transport segments from the manufacturing facility until they have attained the design strength. This shall be verified by cylinder tests on concrete cured with the segments or correlation with maturity curves.

1.10 FIELD CONDITIONS

A. Cold-Weather Placement: Comply with ACI 306R and ACI 306.1 and as follows. Protect concrete work from physical damage or reduced strength that could be caused by frost, freezing actions, or low temperatures.

1. When average high and low temperature is expected to fall below 40 deg F for three successive days, maintain delivered concrete mixture temperature within the temperature range required by ACI 301.

2. Do not use frozen materials or materials containing ice or snow.
3. Do not use calcium chloride, salt, or other materials containing antifreeze agents or chemical accelerators unless otherwise specified and approved in mixture designs.
4. If heat is provided by fired equipment, care shall be taken to prevent the concrete from drying out, and ventilation shall be provided to avoid the risk of health hazards and the carbonation of young concrete. When heating equipment is used, temperature shall be controlled through the use of thermostats to ensure temperature does not rise above 80 deg F.
5. To avoid cracking of the concrete due to sudden temperature changes near the end of the curing period, the protection shall not be completely removed until the concrete has cooled to the temperature differential indicated in ACI 306R.

B. Hot-Weather Placement: Comply with ACI 301, ACI 305R and ACI 305.1, and as follows:

1. Maintain concrete temperature below 80 deg F at time of placement. Chilled mixing water or chopped ice may be used to control temperature, provided water equivalent of ice is calculated to total amount of mixing water. Using liquid nitrogen to cool the batch water or to cool the cement as extracted from the storage silo may be used at the Contractor's option as approved by the Designer.
2. Fog-spray forms and steel reinforcement just before placing concrete.

PART 2 - PRODUCTS

2.1 SEGMENT MOLDS

A. Segment molds shall be steel construction with machined mating surfaces, be of strong and rigid construction, and provide segments to the dimensions and tolerances required.

B. Clearly identify loose mold components that affect the integrity of the mold as being part of the main mold.

C. Ensure that the maximum local irregularity on formed surfaces does not exceed a rounded protrusion of 1/32 inch above the general concrete surface form.

D. Measure completed molds to tolerances that are no more than half that required for the segments on the Agreement Drawings.

E. Use molds that provide smooth and true casting surfaces that are free from irregularities or blemishes.

F. Joints in the molds are required to be watertight.

G. All inserts to form bolt pockets, holes, grout sockets or similar items shall have sufficient strength and an appropriate coefficient of thermal expansion to maintain fabrication tolerances of the segments.

H. Position the circumferential dowel connectors in the molds to provide full engagement of the dowel with compression packing in place.

2.2 CONCRETE MATERIALS

A. ACI Publications: Comply with the following unless modified by requirements in the Agreement Drawings or this Section:
1. ACI 301.
2. ACI 117.

B. Source Limitations: Obtain each type or class of cementitious material of the same brand from the same manufacturer's plant, obtain aggregate from single source, and obtain admixtures from single source from single manufacturer.

C. Cementitious Materials:

1. Portland Cement: ASTM C150, Type I, Type II, Type I/II, Type IV, Type V.
2. Fly Ash: ASTM C618, Class F.
3. Slag Cement: ASTM C989, Grade 100.
4. Silica Fume: ASTM C1240, amorphous silica.
5. Blended Hydraulic Cement: ASTM C595, Type IS (Portland-slag cement), Type IP (Portland-pozzolan cement), Type IT (Ternary blended cement).
6. Minimum and maximum cement replacements levels to be in accordance with Table 5.

D. Normal-Weight Aggregates:
1. Coarse Aggregates:
   a. ASTM C33, Class 3S class coarse aggregate or better, graded. Provide aggregates from a single source with documented service record data of at least 10 years' satisfactory service in similar applications and service conditions using similar aggregates and cementitious materials.
   b. Provide coarse aggregate for concrete that meet the grading requirements of Table 1 and the physical requirements of Table 2.

Table 1: Grading Requirements for Coarse Aggregates

Series/ Class	**Sieve analysis (MTM 109) Total percent passing [a]**							**Loss by washing (MTM 108) % passing**
	1 ½ in	1 in	¾ in	½ in	3/8 in	No.4	No.8	No. 200 [a]
6AA	100	90-100	-	30-60	-			≤1.0 [b]
17A	-	100	90-100	50-75	-	0-8	-	≤1.0 [b]
26A	-	-	100	95-100	60-90	5-30	0-12	≤1.0 [b]

[a] based on dry weights
[b] Loss by Washing will not exceed 2.0 percent for material produced entirely by crushing rock, boulders, cobbles, slag, or concrete

Table 2: Physical Requirements for Coarse Aggregates

Properties	**Test standard**	**Physical requirements for coarse aggregates (Gravel or Stone)**	**Notes**
Crushed material, % min	MTM 117	-	
Loss, % max, Los Angeles Abrasion	MTM 102	40	
Soft particles, % max	MTM 110	2.0	
Sum of soft Particles and Chert, % max	MTM 110	4.0	
Freeze-Thaw dilation, % per 100 cycle max	MTM 115	0.010	[a]
Total acid soluble sulfates %, max	EN 1744	0.2	
Iron pyrite and pyrrhotite %, max	EN 1744	0.1	[b]

[a] If the relative density OD is more than 0.04 less than the relative density OD of the most recently tested freeze-thaw sample, the aggregate will be considered to have changed characteristics and be required to have a new freeze-thaw test conducted prior to use
[b] If petrography detects the presence of iron pyrites or pyrrhotites a maximum total sulfur content of 0.1 % apply

c. Maximum Coarse Aggregate Size: Refer to for nominal size in Table 4.
d. The maximum aggregate size shall meet the requirements of ACI 301.

2. Fine Aggregate for Concrete: Furnish conforming to the following sections:
   a. Natural Sand, 2NS which is the result from the natural disintegration of rock.
   b. Manufactured Sand, 2MS produced by totally crushing rock or gravel.
   c. Stone Sand, SS which is manufactured from stone meeting all the physical requirements of Table 2. Stone sand is permitted only in structural concrete not exposed to vehicular traffic.
   d. The material must be clean, hard, durable, uncoated particles of sand, free from clay lumps and soft or flaky material.
   e. Grading: Uniformly grade the aggregate from coarse to fine in accordance with Table 3.

Table 3: Grading Requirements for Fine Aggregates

Series/ Class	Sieve analysis (MTM 109) total percent passing [a]							Loss by washing (MTM 108) % passing
	3/8 in	No.4	No.8	No.16	No.30	No.50	No.100	No. 200 [a], [b]
2NS[c]	100	95-100	65-95	35-75	20-55	10-30	0-10	0-3.0
2SS [d]	100	95-100	65-95	35-75	20-55	10-30	0-10	0-4.0
2MS[c]	-	100	95-100	-	-	15-40	0-10	0-3.0

[a] Test results based on dry weights
[b] Use test method MTM 108 for Loss by Washing Loss
[c] Max. allowed fineness modulus variation of ± 0.20. Aggregate having a fineness modulus differing from the base fineness modulus of the source by the amount exceeding the maximum variation of ± 0.20, will be rejected. Use ASTM C136. The base fineness modulus will be supplied by the aggregate producer at the start of each construction season and be within the range of 2.50 to 3.35. The base FM, including the permissible variation, will be within the 2.50 to 3.35 range
[d] Quarried carbonate (limestone or dolomite) cannot be used for any application subject to vehicular traffic.

   f. Test for organic impurities in accordance with AASHTO T21: The aggregate must not produce a color darker than Organic Plate No. 3 (Gardener Color Standard No.11). Designer may approve the use of fine aggregate that fails the test for organic impurities based on one of the following:
      1) The discoloration resulted from small quantities of coal, lignite, or similar discrete particles, or
      2) The tested concrete develops a relative seven-day strength of at least 95 percent in accordance with AASHTO T71.
   g. Fine aggregate 2NS, 2SS, and 2MS must meet fineness modulus requirements in Table 3.
   h. Do not use crushed portland cement concrete fine aggregate in concrete mixtures.

3. Alkali-silica Reactivity: The potential for deleterious alkali-aggregate reactivity for fine and coarse aggregates shall be assessed in accordance with ASTM C1778 for Structural Class S4 for aggregates with a maximum aggregate reactivity class of R2. Adopt one of the following approaches to reduce the risk of deleterious alkali-aggregate reactivity:
   a. Prescriptive Approach in accordance with ASTM C1778 and submit alkali-silica reactivity with cementitious material to ASTM C1567, performed on the approved mix design. Do not use lithium compounds as mitigation measures. A limiting expansion of ≤ 0.10 percent at 16 days after casting applies.
   b. Performance approach in accordance with ASTM C1778.

E. Water: ASTM C94, ASTM C1602 and potable.

F. Chemical Admixtures: Certified by manufacturer to be compatible with other admixtures and that do not contribute water-soluble chloride ions exceeding those permitted in hardened concrete. Do not use calcium chloride or admixtures containing calcium chloride.

1. Water-Reducing Admixture: ASTM C494, Type A.
2. Retarding Admixture: ASTM C494, Type B.
3. Water-Reducing and Retarding Admixture: ASTM C494, Type D.
4. High-Range, Water-Reducing Admixture: ASTM C494, Type F.
5. High-Range, Water-Reducing and Retarding Admixture: ASTM C494, Type G.
6. Air Entraining Agents: ASTM C260.
7. Unless otherwise shown on the Agreement Drawings, the amount of air-entraining agent used in each concrete mix shall be such as will affect the entrainment of the percentage of air, shown in Table 4: Concrete Mixtures, in the concrete as discharged from the mixer or pumper discharge hose if applicable.
8. The level of exposure shall be as shown in Table 4.
9. When a batch of concrete delivered to the project does not conform to the minimum specified air content, an air-entraining admixture may be added, one time only for the batch. After the admixture is added, the concrete shall be remixed for a minimum of 20 revolutions of the mixer drum at mixing speed. The concrete shall then be retested and if found acceptable, may be placed in accordance with this Section.

G. Set-Accelerating Corrosion-Inhibiting Admixture: Commercially formulated, anodic inhibitor or mixed cathodic and anodic inhibitor; capable of forming a protective barrier and minimizing chloride reactions with steel reinforcement in concrete and complying with ASTM C494, Type C.

H. Non-Set-Accelerating Corrosion-Inhibiting Admixture: Commercially formulated, non-set-accelerating, anodic inhibitor or mixed cathodic and anodic inhibitor; capable of forming a protective barrier and minimizing chloride reactions with steel reinforcement in concrete.

2.3 CONCRETE MIXES

A. The following concrete mixes are required for the PCTL:

Table 4: Concrete Mixtures

Application/ Component		**Precast Tunnel Lining**
Design Service Life (Years)		100
Concrete Class		Class P (HPC)
Compressive Strength[a] (psi)		8,500 (Type A) 10,000 (Type B)
Project Exposure Class[b]		S1 + XC3 + XD2 + F2
Maximum Aggregate size		1 inch
Allowed cement types		Table 5
Minimum cementitious material content (lbs/cy)		611
Maximum cementitious material content (lbs/cy)		1000
Maximum water to cementitious materials ratio		0.40
Temperature of fresh Concrete (minimum) (°F)		40 ºF (5ºC)
Temperature of fresh Concrete (maximum) (°F)		85 ºF (30 ºC)
Durability performance requirements	Chloride ion penetrability ASTM C1202 Rapid Chloride Migration (NT Build 492) [c]	700 Coulomb @ 56 days Table 6
	Accelerated carbonation test $R_{ACC,0}^{-1}$ [d]	≤962.5 (mm^2/year)/($kgCO_2$)
	Air content % (ASTM C231) Air-void spacing factor (ASTM C457) [e] Resistance to F/T in lieu of air entrainment [f]	4.5 – 7.5 % [e] Durability Factor ≥ 80%
Shrinkage of hardened concrete (ASTM C157) [g]		≤ 0.040%
Heat of hydration control and DEF Prevention	Maximum temperature, Tmax Temp. gradient center to surface	Tmax ≤ 176 ºF (80 ºC) ΔTdif ≤ 35 ºF (20 ºC)
	Control of sulfates and aluminates	C_3A ≤ 8% (as proportion of clinker) SO_3 ≤ 3% (as proportion of the cement)
Workability (method and target value)		[h]
Slump with or without Superplasticizer[h]		3 1/4±1 1/4
Residual flexural tensile stress $f_{R,1}/f_{R,3}$ in accordance with BS EN 14651.		$f_{R,1}$ = 630 psi / $f_{R,3}$ = 440 psi (Type A) $f_{R,1}$ = 680 psi / $f_{R,3}$ = 480 psi (Type B)
Peak tensile splitting strength f_t per Standard Test Method for Evaluating the Tensile Performance of Fiber-Reinforced Concrete Using Cylindrical Specimens with Double-Punch Loading		615psi for Type A segments 665psi for Type B segments.

NOTES

[a] Minimum compressive strength is required for strength. Actual strength may exceed this due to requirements for durability. The concrete mix shall possess satisfactory workability to enable proper mixing, transporting, placing, and compaction without adversely affecting the concrete strength and durability.

[b] Project exposure classes are defined as follows;
Sulfates: S0, S1… (ACI 301) Chlorides: XD1 Airborne, XD2 Submerged, XD3 Splash (EN 206)
Carbonation: XC1, XC2… (EN 206) Freezing-thawing: F0, F1, F2… (ACI 301)

[c] $D_{RCM,0}$ values in $\cdot 10^{-12}$ m^2/s determined at 28 days in accordance with Nordtest Build 492.

[d] Accelerated carbonation test to fib-34, section B.1.2.5.2. A minimum of two prism specimens with dimensions 4 in. (100 mm) in width, 4 in. (100 mm) depth and 19.7 in. (500 mm) in length. Total test duration is 56-days; including 7-days water curing and 21 days air drying in standardized laboratory climate; shall be placed in a carbonation chamber with a CO2 concentration of Cs = 2.0 vol% during 28 days.

[e] The air void system is considered to be satisfactory when the average spacing factor is ≤ 230 µm, with no single test greater than 260 µm and the air content is > 3.0%. For mixes with w/c ≤ 0.36, the average spacing factor shall not exceed 260 µm, with no single test > 300 µm.

[f] As an alternative to air entrainment, equivalent performance shall be demonstrated through freezing and thawing tests of concrete with fibers and no-air entrainment. The concrete shall have a durability factor of at least 80% when tested in accordance with Procedure A (ASTM C666, Procedure A, 300 cycles), except that the age at testing shall be 56 days. Specimens shall be prisms at least 3 in. (75 mm) but not more than 5 in. (125 mm) in width or depth and at least 11 in. (280 mm) but not more than 16 in. (400 mm) in length.

[g] Maximum concrete shrinkage for specimens cast in laboratory from trial batch, as measured at 21-days drying age. Maximum concrete shrinkage for specimens cast in factory shall not exceed trial batch maximum shrinkage requirement by more than 25%.

[h] Contractor may adjust slump, slump flow and other workability aspects of mixes to suit placement methods while maintaining specified hardened concrete properties. Concrete shall not show visible signs of segregation.

B. Blended hydraulic cement types or equivalent combinations with supplementary cementing materials levels to be in accordance with Table 5.

Table 5: Permitted Cement Types and Equivalent Combinations

Type	Designation of Blended Cement to ASTM C595	Combination Type I/II/IV/V + SCM [a]	Type description	Composition (percentage by mass of total cementitious material)		
				Percentage of supplementary cementitious materials in blended cements or concretes		
				Fly-ash	Blast-furnace slag	Silica fume
				F	S	SF
A	Type IP	I/II + fa	Portland-fly ash	15 - 35	-	-
B	IT(S)(P) [b]	I/II + slag + fa	Ternary blended cement	15 - 25	25-35	-
C	IT(P)(SF) [c]	I/II + fa + sf	Ternary blended cement	15 - 30	-	5 - 8
D	IT(S)(SF) [d]	I/II + slag + sf	Ternary blended cement		20 - 45	5 - 10
E	Type S	I/II + slag	Blast-furnace cement	-	70 - 80	-
G	Type IP	I/II + sf	Portland-silica fume	-	-	10 - 11

[a] When used in combination with SCMs, Type I/II cements are preferred. They may be replaced with Type IV or Type V where required
[b] Total cement replacement not to exceed 60%.
[c] Total cement replacement not to exceed 35%.
[d] Total cement replacement not to exceed 45%.

C. Resistance to chloride attack to meet the performance requirements of Table 6. Test concrete during laboratory trials and production.

Table 6: Chloride Migration Coefficient Requirements

Type	Designation of Blended Cement to ASTM C595	Combination Type I/II/IV/V + SCM [a]	Concrete cover to extra-dos face		Chloride migration coefficient, $D_{RCM,0}$ (NT492, 28 days) [x10^{-12} m^2/s]	
			Nominal cover, c_{nom} [in.]	Deviation, $\Delta_{c,dev}$ [in.]	Average [e],[f]	Maximum [f]
A	Type IP	I/II + fa	1 ½ in. (38.1 mm)	5/64 in. (2.0 mm)	≤ 5.6	≤ 7.0
B	IT(S)(P) [b]	I/II + slag + fa			≤ 4.5	≤ 5.7
C	IT(P)(SF) [c]	I/II + fa + sf			≤ 4.0	≤ 5.0
D	IT(S)(SF) [d]	I/II + slag + sf			≤ 4.0	≤ 5.0
E	Type S	I/II + 70%slag			≤ 1.5	≤ 1.9
G	Type IP	I/II + sf			≤ 4.3	≤ 5.4

Types A, B, C, D, E withstand chloride concentrations up to ~15 g/L
Type G withstands chloride concentrations up to ~7 g/L
Notes (a),(b),(c) and (d): See Table 5.

[e]Trial batch: Limit chloride migration coef. for at least 3 specimens cast in laboratory (without fibers) from trial batch, as measured at 28-days age using NT 492.
[f] Production: average chloride migration coef. (without fibers), as measured at 28-days age using NT 492 for at least 3 specimens cast in factory. Maximum RCM values apply to individual specimens cast in factory.

2.4 REINFORCEMENT STEEL

A. Low-Alloy-Steel Reinforcing Bars: ASTM A706, deformed. Ship all weldable reinforcing with clear tags.

B. Fabricate curved or straight welded wire fabric ladders and/or mesh conforming to ASTM A1064 using electro-resistance welding.

C. Perform manual welds conforming to the procedures in AWS D1.4. Weld rebar cage(s) for assembly such that welds maintain the integrity and capacity of rebar.

D. Use qualified welders for manual welds according to AWS D1.4 unless agreed with Designer that welds are not in a location that will impact the integrity and capacity of rebar.

E. Tie Wire: minimum 16 gage black annealed wire.

2.5 STEEL FIBER REINFORCEMENT

A. Liners shall incorporate steel fiber reinforcement, consisting of deformed steel fiber Type 1 in accordance with ASTM A820. Produce fibers from cold drawn wire.

B. Fibers may be collated with fast acting water-soluble glue or may be uncollated individual fibers.

C. Store fibers in dry sealed containers until required for use. Keep fibers free from corrosion, oil, grease, chlorides, and deleterious materials that may reduce the bond between the fibers and the concrete.

D. The required minimum length of the fibers is 2 3/8 inches.

E. The required aspect ratio of the fibers is in the range 60 l/d to 80 l/d.

F. The required minimum tensile strength of the fibers is 150 ksi.

G. Minimum dosage of steel fibers is 40 lb/CY (23 kg/m^3). Steel fiber reinforcement dosage shall be selected through testing to attain specified residual flexural tensile strength.

H. Use fibers that can be uniformly distributed in the concrete and do not tend to form fiber balls during batching and mixing.

2.6 POLYPROPYLENE FIBERS

A. Liners shall incorporate monofilament polypropylene fibers conforming to ASTM C1116, manufactured in an ISO9001 accredited factory.

B. Polypropylene fibers shall be 32 micrometers in diameter and between 6 to 12 mm (0.25 and 0.5 inches) in length.

C. Required dosage for polypropylene fibers is anticipated to be between 1.7 to 3.4 lb/CY (1 to 2 kg/m^3) and will be determined by the fire tests. In developing mix design, note that the use of carbonate aggregates will typically allow the polypropylene dosage to be lower than with other types of aggregate.

2.7 FORM RELEASE AGENT

A. Utilize a commercially formulated form-release agent with rust inhibitor that does not bond with, stain, or adversely affect concrete surfaces and does not impair subsequent treatments of concrete surfaces.

2.8 CURING COMPOUNDS

A. Materials for curing concrete shall meet the requirement of ASTM C309, C1315 or C171.

B. Where used, curing compounds shall meet the requirements of ACI 533.2R and ACI 517.2R.

C. Ensure that any curing compound does not affect the performance of the gaskets.

2.9 CONCRETE PERMEABILITY

A. The non-steady-state migration coefficient (DRCM) determined by Nordtest 492 shall not exceed a mean of $1.1x10^{-11}$ ft^2/s and a maximum of $1.4x10^{-11}$ ft^2/s.

B. Carbonation to fib Bulletin No. 34 shall be less than 1577.9 $(mm^2/year)/(kgCO_2)$ in concrete mixes with more than 50% slag, and less than 962.5 $(mm^2/year)/(kgCO_2)$ in all other concrete mixes. The result shall be the average of at least two prisms or two cores. At the end of CO_2-loading split specimens into two inch slices and spray with an indicator solution. Determine the average of five readings on each face. The maximum allowable single value per test face is the expected 95%-quantile result.

C. When tested to USACE CRD-C48, no passage of water through samples when exposed to a vertical water head equal to 200 psi (460 foot head pressure) for 14 days.

2.10 SEGMENT TRACEABILITY

A. Each segment shall have segment type and mold number cast into the intrados surface.

B. Each segment shall be identified on both the intrados surface and the circumferential joint edge using durable UPC barcode labels containing the following data:
   1. Unique segment ID number.
   2. Segment type.
   3. Date and time of casting.
   4. Type of reinforcement.
   5. Project name.

C. Segment Tracking Database:
   1. Maintain a segment tracking database system for all segments. Provide capability of real-time data acquisition of the segment production, digital warehouse management and the creation of reporting, delivery and loading documents from the system.
   2. Suppliers: Subject to compliance with requirements, provide products by one of the following or similar approved:
      a. VMT.
      b. Bab-Ing.
   3. All functions, or specific elements, of the Segment Tracking Database can be incorporated within the Tunnel Monitoring and Documentation System specified in Section 317119 “Excavation by Tunnel Boring Machine”. Alternatively, the Segment Tracking Database can be accomplished by using two or more separate databases (e.g. one for general segment manufacturing and one for concrete laboratory test results) as long as the information can be linked by the unique segment ID number.

D. Each unique segment ID number shall refer to a dataset in the database containing not less than the following data:
   1. Unique segment ID number.
   2. Segment Type.
   3. Mold number.
   4. Type of reinforcement.
   5. Unique reinforcement cage ID number.
   6. Concrete batch information.
   7. Concrete tests and results.
   8. Date and time of major production steps, including placing the reinforcement cages and casting.
   9. Temperature and relative humidity in factory at time of casting.
   10. Age of the segment.
   11. Status of the segment (e.g. produced, in storage, delivered, installed).
   12. Inspection and repair history including photographical damage documentation, damage classification and repair type.

E. Digitally record all major production, QC and logistics processes such as molding, concreting, demolding, storage, delivery and tunnel installation by using fixed and/or mobile barcode scanner devices. Record name of the inspector/individual performing each step of the segment inspection.

F. Integrate system-based logic to provide daily and weekly manufacturing reports and ensure compliance with quality requirements such as curing duration.

2.11 GASKETS

A. Gaskets shall be dense elastomeric synthetic rubber type, free of pitting, porosity, blisters and other imperfections, manufactured as a continuous frame, with mitered and injection vulcanized molded gasket corners (no glued corner assemblies are permitted) to provide uniform gasket thickness along the entire length of mating surfaces.

B. Gaskets shall be manufactured by extrusion to form a profile with appropriate void spaces within the section to enable the gasket to be fully compressible within the groove formed in the concrete segments. The gasket shall still be capable of further compression when its top surface is level with the top of the gasket groove. The percentage of gasket groove filled shall not exceed 95% of the cross section of the groove area at full closure of the segments. Consider compression packing thickness and its compression under the maximum TBM thrust loading in the gasket design.

C. The gasket shall function under all combinations of packing and displacement encountered in the fully assembled ring.

D. Chemical Resistance: The intrados gasket shall not degrade or loose effectiveness while compressed in the tunnel lining when exposed on one side for a duration of no less than 45 days to the compounds in Table 7, as defined by www.crudemonitor.ca:

Table 7: Intrados Gasket - Potential Exposure Compounds

Product Identifier	UN-Number	Synonyms	Sign
Petroleum Crude Oil—Light Synthetic	UN1268	Premium Synthetic (PSY)	PSY
		Synthetic Sweet Blend (SYN)	SYN
		Hardisty Synthetic Crude (HSC)	HSC
Petroleum Crude Oil—Sour	UN1267	Medium Sour Blend (MSB)	MSB
		Central Alberta Pipeline (CAL 1)	CAL1
		Pembina Light Sour (PLS 1)	PLS1
		Gibsons Light Sour (GLS 1)	GLS1
		Pembina Low Sour (PLO 1)	PLO1
		Gibson Sour (MGS 2)	MGS2
		Kinder Morgan High Sour (KHE 2)	KHE2
		Pembina High Sour (PHO 2)	PHO2
		Peace Pipe Sour (SPR 2)	SPR2
		Rangeland Sour (RSO 2)	RSO2
		Gibsons High Sour (GHE 2)	GHE2
		Hardisty Light (MBL 3)	MBL3
		Manitoba Medium (MM 4)	MM4
		Wespur Midale (MSM 4)	MSM4
		Tundra Light Sour (MLS)	MLS
		Moose Jaw Tops (MJT)	MJT
		Midale (M)	M
		Light Sour Blend (LSB)	LSB
COED NGL at Edmonton	UN1075		
NSB/NSA Crude	UN1267		
High Sweet Clearbrook	UN1267	Bakken Crude Oil	
		High Sweet Clearbrook (UHC)	UHC
		Hydrocarbons of Petroleum	
		North Dakota Sweet (NSW)	NSW
Shell Synthetic Crude Blend	UN1268	SSX	
Petroleum Crude Oil—Sweet	UN1267	Mixed Sweet Blend (MSW)	MSW
		Pembina (P)	P
		Gibson Light (MGL)	MGL
		Joarcam (MLN)	MLN
		Pembina Sweet Blend (PSB)	PSB
		Rangeland Sweet (RSW)	RSW
		Rainbow Light (RA)	RA
		Federated (FD)	FD
		Light Smiley (MSY)	MSY
		Manitoba Sweet Tundra (MST)	MST
		Peace Pipe Light (MPR)	MPR
		Kinder Morgan Sweet (KSW)	KSW
		Redwater (RW)	RW
		HCT Sweet Blend (HSW)	HSW
		Gibsons Mixed Blend Sweet (GSW)	GSW
		Plains Sweet Regina (PSR)	PSR
		BP SW (SWB)	SWB

E. The gasket shall not degrade or lose its effectiveness when exposed to alkalinity of the tunnel lining concrete and backfill grout around the outside of tunnel and shall perform its intended function considering stress, relaxation, aging and shrinkage.

F. Gasket material shall not suffer any adverse effects when exposed to groundwater at pressures up to the minimum working water pressure.

G. If segments with mounted gaskets are to be stored out of doors and exposed to the elements, including direct sunlight, provide a written statement from the gasket manufacturer that such exposure will not affect the performance of the gaskets.

H. Material Properties of fabricated gasket shall be certified by gasket manufacturer to meet the following minimum requirements:
   1. Tensile Strength: ASTM D412, greater than 1,450 psi.

2. Elongation: ASTM D412, greater than 300 percent.
3. Hardness: ASTM D2240, Durometer A; As defined by gasket manufacturer, plus or minus 5.
4. Compression Set: ASTM D395; Method B:
   a. Short Term Test: Less than 20-percent compression set after 25 percent initial vertical compression at 160 degrees F for 22 hours.
   b. Long Term Test: Less than 20-percent compression set after 50 percent initial vertical compression at 73 degrees F for 70 hours.
5. Aging: ASTM D573, 168 hours at 160 degrees F. Limit changes in material properties as follows:
   a. Tensile Strength: -20% to 10%.
   b. Elongation: -30% to 10%.
   c. Hardness: -5% to 8%.
6. Water Absorption: ASTM D471, 48 hours at 158 degrees F, maximum 10 percent increase by weight. Use distilled water for the standard test.
7. Oil Absorption (EDPM only): ASTM D471, 70 hours at 158 degrees F, Oil No. 3, maximum changed weight to be 110 percent of original weight.
8. Ozone Resistance: ASTM D1149, by method described in ASTM D813 Procedure A, with the following stipulation: No surface cracking of un-tensioned specimen (zero-percent elongation) when immersed in a 200 parts per 100,000,000 ozone solution for 100 hours at room temperature and 55 percent humidity.
9. Load-Displacement Behavior: No more than a peak load of 4.5 kips per linear foot (65 kN/m) on gasket groove and a relaxation of at least 30% within the five minutes of loading, both in linear sections and on the corners, under any possible combination of manufacturing and installation tolerances.
10. Stress Relaxation:
    a. For material sample tested at room temperature and 40 percent vertical deflection, with a 2-minute measured stress set equal to 100 percent, the residual stress shall be greater than 85 percent after 14 continuous days of testing.
    b. Residual contact stress after 100 years shall be greater than 55% of the measured stress.
11. Restorative capacity: Greater than 90%.

I. Manufacturing tolerances shall be according to DIN ISO 3302-01, tolerance class E2.

J. Use gasket adhesive that will remain elastic and apply adhesive in accordance with the gasket supplier recommendations.

2.12 APPURTENANCES

A. Durability:
   1. All grout sockets, grout plugs, threaded plastic inserts, guide rods, and related embedded items shall account for any long-term relaxation in the materials during the 100-year design life and shall function under conditions of a temperature range of -32ºF to 100ºF (-36 to 38ºC).

B. Bolts and Bolt Inserts:
   1. All permanent bolts and washers shall conform to ASTM F3125.

C. Grout Sockets:
1. Grout sockets shall be of a type successfully used on at least five tunnel projects in the previous 5 years.
2. If the grout socket is used for check grouting, or for any other reason that compromises the sealing capacity of the socket, then install a grout plug.
3. Grout sockets and plugs shall be capable of resisting the working pressure without leaking on either the inside through the plug or outside along the socket/concrete interface. Each grout socket shall include a hydrophilic washer near its base.
4. Grout sockets shall be capable of resisting a pressure of 1.5 times the working pressure during check grouting without failure, including stripping of the inner threads or outer ribs.
5. Grout plugs shall include a hydrophilic washer.
6. Arrange the socket such that the grout plug in its final position does not protrude into the tunnel beyond the inner surface of the segment.

D. Guide Rod:
1. Guide rods shall be of a type successfully used on at least five tunnel projects in the previous 5 years.
2. Design life shall be no less than 100-year as certified by supplier.

E. Reinforcement Spacers/Chairs:
1. Do not use plastic spacers/chairs.
2. Concrete spacers should have the same minimum compressive strength and durability as the concrete mix design.
3. Saturate all spacers with clean water for at least 24 hours prior to use.
4. Spacers shall be in a moist condition and not allowed to appreciably dry after being fixed to reinforcement cages before the concrete is cast.

2.13 COMPRESSION PACKING

A. Packing shall have a maximum thickness of 5/32 inches.

B. Packing material shall be high density polyurethane (HDPE), manufactured by Tunneling Accessories, or approved equal.

C. Packing shall extend no closer than 1/4 inch from the inside edges of the gasket grooves and cover no less than 90 percent of the bearing area.

2.14 FOAM STRIP

A. Foam strips shall be compressible closed cell material capable of preventing backfill grout from entering joints between segments.

2.15 REPAIR MATERIALS

A. Epoxy Resin: Low-viscosity 2-component injection resin based on epoxy meeting class U(F1) W(2) (1) (8/30) in accordance with ASTM C881 Grade 1, Class C, Types I, II.

B. Sand Cement Mortar: Two-component, polymer-modified, cementitious, non-sag mortar exceeding the requirements of ASTM C928, Class R2 for structural concrete repair. The strength at 28 days should match that of the segment concrete.

C. Non-shrinkage or fiber reinforced two-component epoxy resin coarse mortar (PC mortar) meeting the following requirements:
   1. Exceeding the requirements of ASTM C928, Class R2 for structural concrete repair.
   2. Suitable for use on vertical and overhead areas.
   3. Suitable for vertical applications having thicknesses greater than two inches.
   4. Properties (compressive strength, indirect tensile strength, E-Modulus, shrinkage and coefficient of thermal expansion, etc.) that are compatible with the segment concrete.
   5. Consist of factory proportioned and pre-bagged materials.
   6. Mortar shall not contain chlorides, nitrates, added gypsum, added lime, or high alumina cements.
   7. Application time (working time) for horizontal and vertical repairs shall be at least 45 minutes after mixing and shall have set times suitable for the repair work in hand. Color of the finished material shall be concrete grey.

2.16 SOURCE QUALITY CONTROL

A. At a minimum, include the following items in the Inspection and Test Plan:
   1. Surveillance:
      a. Not used.
   2. Review:
      a. Cement certificates.
      b. Silica fume certificates.
      c. Fly ash certificates.
      d. GGBFS certificates.
      e. Admixture certificates.
      f. Aggregate testing records.
   3. Verification:
      a. Not used.
   4. Witness Point:
      a. Not used.
   5. Hold Point:
      a. Not used.

PART 3 - EXECUTION

3.1 MIX DESIGNS

A. Prequalify all the mixes to be used on this project by preparing Design Mixtures and preparing and submitting a Prequalification Mix Development Report.

B. Design Mixtures: Prepare design mixtures for each type and strength of concrete, proportioned on the basis of laboratory trial mixture or field test data, or both, according to ACI 301. Submit alternate design mixtures when characteristics of materials, project conditions, weather, test results, or other circumstances warrant adjustments. Use ACI 211.1 as a guide for determining

mix proportions for concrete, except for concrete to be pumped. For pumped concrete, use the mix proportions recommended in ACI 304.2R.

1. Use a qualified testing laboratory for preparing and reporting proposed mixture designs based on laboratory trial mixtures.
2. Perform all tests using a testing laboratory certified in accordance with the requirements of ASTM C1077.
3. Sample and test in accordance with ACI 304R.

C. Cementitious Materials: Limit percentage, by weight, of cementitious materials other than portland cement in concrete in accordance with Table 4: Concrete Mixtures.

D. Limit water-soluble, chloride-ion content in hardened concrete to 0.06 percent by weight of cement.

E. Limit acid-soluble, chloride-ion content in hardened concrete exposed to de-icing salts or chlorides ions from other sources to 0.10 percent by weight of cement per ASTM C1152.

F. Admixtures: Use admixtures according to manufacturer's written instructions.

1. Use water-reducing, high-range water-reducing or plasticizing admixture in concrete, as required, for placement and workability.
2. Use water-reducing, -retarding or -hydration stabilizing admixtures when required by high temperatures, low humidity, or other adverse placement conditions.
3. Use water-reducing admixture in pumped concrete, concrete for heavy-use industrial slabs and parking structure slabs, concrete required to be watertight, and concrete with a w/c ratio below 0.50.
4. Use corrosion-inhibiting admixture in concrete mixtures where indicated.

G. Prequalification Mix Development Report: Provide report covering development of concrete mixes and final selection. Report shall cover the following as a minimum:

1. The nature and source of each constituent material.
2. Cement mill test report and test results.
3. Fly ash test results as specified by ASTM C618.
4. GGBFS tests results as specified in ASTM C989.
5. Silica fume test results as specified in ASTM C1240.
6. Aggregate test results as specified by ASTM C33.
7. Water test results as specified by ASTM C1602.
8. The source of supply of concrete and any proposed alternative sources.
9. The mix designs for the different aspects of construction giving proposed mix proportions and quantities of each constituent material per cubic yard of compacted concrete.
10. Details of admixtures to be used.
11. Evidence of suitability of proposed mix proportions to meet the requirements of this Section, based on prequalification testing.
12. Certification of quality assurance.
13. Information on aggregates required by this Section.
14. Workability and workability retention of concrete mix.
15. Confirmation of the strength and density properties of the concrete.
16. Evidence the ready-mix plant(s), equipment, and all materials to be used in the concrete comply with the requirements of ASTM C94.
17. All other information regarding constituent materials, including QA such as test certificates, required by this Section.

18. Provide the following test results performed by a testing laboratory for each mix type in the Prequalification Mix Development Report:
    a. Concrete compressive strength at 3, 7, 28 and 56 days.
    b. Splitting tensile strength.
    c. Water soluble and acid-soluble chloride ion content of mix to ASTM C1152.
    d. Chloride ion penetrability to ASTM C1202.
    e. Rapid Chloride Migration Test to NT Build 492.
    f. Alkali-aggregate reaction resistance to ASTM C1260/1567 or as required by ASTM C1778.
    g. Coefficient of thermal expansion.
    h. Shrinkage at 7, 21, 28 and 56 days.
    i. Heat of hydration.
    j. Entrained air-void system: ASTM C457, ASTM C856.
    k. Freeze-thaw resistance: ASTM C666.
    l. Fresh concrete temperature and control of heat of hydration.
    m. Workability.
    n. Setting time.
    o. Steel Fiber Reinforced Concrete:
        1) Results from testing of twelve beam samples at 28 days and/or 56 days to BS EN 14651. Materials approval associated with residual flexural tensile strength requirements shall be based on characteristic values calculated assuming a normal distribution.
        2) Check failed specimens to ensure the random distribution and alignment of the steel fibers. Should the fiber alignment or distribution be noticeably nonrandom to improve the results from the testing, repeat the tests.
        3) Demonstrate the fiber content by taking a random sample of 0.25 cubic feet of the concrete mix and separating out the fibers. Collect, dry, and weigh the fibers. The fiber content is deemed acceptable if the following are satisfied:
            a) The average fiber content from a set of three samples is greater than the design fiber content.
            b) No individual sample has a fiber content less than 80 percent of the design fiber content.
19. Notify the Company one week in advance of trial mix work.
20. Perform trial mix work in the presence of the Company.
21. Do not place production concrete until the trial mix requirements are met as specified.

H. If existing mix designs are proposed to be used, provide the test results listed in Section 1.8A based on documentation less than 1 year old at start of the project.

3.2 PRODUCTION BATCHING, MIXING AND DELIVERY

A. The batching plant requirements for storage and handling of materials, scales, and measuring systems shall be in accordance with ACI 304R.

B. Mixing equipment, operation of mixers, maintenance of mixers, time and rate of mixing, types of mixers, and testing shall meet the requirements of ACI 304R.

C. Complete measuring and batching of materials at a batching plant. All materials in the concrete mix shall be accurately measured in accordance with ACI 304R.

D. Portland Cement: Either sacked or bulk cement may be used. No fraction of a sack of cement shall be used in a batch of concrete unless the cement is weighed. Bulk cement shall be weighed on scales separate and distinct from the aggregate hopper or hoppers. Batching shall be such that the accuracy of batching shall be plus or minus one percent of the required weight.

E. Water: Unless water is to be weighed, the water-measuring equipment shall include an auxiliary tank from which the measuring tank is filled. In lieu of the volume method, use of a water-metering device is permitted.

F. Aggregates:
1. Aggregates shall be handled from stockpiles or other sources to the batching plant in such a manner as to secure a uniform grading of the material. Aggregates that have become segregated, or mixed with earth or foreign material, shall not be used. Batching shall be so conducted as to result in the weights of material required for each type aggregate within a tolerance of 2 percent.
2. Free water contents of the coarse and fine aggregates shall be continuously tested and the concrete mixture adjusted for moisture conditions of the aggregate in order to meet the designated water/cement ratio.

G. Fine Aggregate: The proportion of fine aggregate shall be between 36 and 44 percent by volume of the total aggregates in the concrete.

H. Mixing:
1. Ready-mixed concrete shall be either “central mixed” or “shrink mixed” concrete as defined in ASTM C94. “Truck mixed” concrete as defined in ASTM C94 is not permitted. Mixing time shall be measured from the time water is added to the mix, or cement contacts the aggregate. All concrete shall be homogeneous and thoroughly mixed, and there shall be no lumps or evidence of undispersed cement. Mixers and agitators which have an accumulation of hard concrete or mortar shall not be used. Ready-mixed concrete shall be mixed and transported in accordance with ASTM C94.
2. The temperature of mixed concrete, immediately before placing shall not be less than 50 degrees Fahrenheit or more than 90 degrees Fahrenheit. Aggregates and water shall be heated or cooled as necessary to produce concrete within these temperature limits. Neither aggregates nor mixing water shall be heated to exceed one 150 degrees Fahrenheit.
3. The time elapsing from the time water is added to the mix (or the cement comes in contact with aggregate) until the concrete is deposited in place shall not exceed 60 minutes when the concrete is hauled in non-agitating trucks, nor more than 90 minutes when hauled in truck mixers or truck agitators.
4. The batch shall be so charged into the drum that a portion of the mixing water shall enter in advance of the cement and aggregates. The flow of water shall be uniform and all water shall be in the drum by the end of the first 1/4 of the specified mixing time.
5. Cement shall be charged into the mixer by means that will not result in loss of cement because of the effect of wind, or in accumulation of cement on surfaces of hoppers or in other conditions which reduce or vary the required quantity of cement in the concrete mixture.
6. Add air entrainment and chemical admixtures as solutions. Correct operation of dispensers shall be verified daily.

I. Transporting Mixed Concrete; Mixed Concrete or Truck Mixers:
1. Concrete delivery equipment and control of concrete slump, air content, temperature, and other records shall be in strict accordance with ACI 304R.

2. Transporting of mixed concrete shall conform to ASTM C94. Non-agitating delivery equipment shall not be used.
3. Truck agitators shall be loaded not to exceed the manufacturer's guaranteed capacity. Maintain the mixed concrete in a thoroughly mixed and uniform mass during hauling.
4. No additional mixing water shall be incorporated into the concrete during hauling or after arrival at the delivery point, unless approved by the Designer.
5. Each load of ready mixed concrete delivered at the job shall be accompanied by the ticket in accordance with Article Delivery, Storage, and Handling.
6. Only the concrete vendor or designated representative is permitted to add admixtures to the concrete after batching. Admixtures added to the mix at the construction site shall be measured to the precise amounts listed in the approved mix design. The delivery ticket shall be reviewed so the amount of admixture added on-site is proportional to the size of the load. After the addition of the admixture, the concrete shall be mixed in the truck to uniformly distribute the admixture. The amount and type of admixture added on-site shall be recorded on the delivery ticket and retained for submittal to the Company.

3.3 REINFORCEMENT CAGES

A. Comply with CRSI's "Manual of Standard Practice" for fabricating, placing, and supporting reinforcement.

B. Clean reinforcement of loose rust and mill scale, earth, ice, and other foreign materials that reduce bond to concrete.

C. Accurately position, support, and secure reinforcement against displacement. Locate and support reinforcement with bar supports to maintain minimum concrete cover.

D. Weld reinforcing bars according to ASTM A1064 for automated welding and perform welding procedures in accordance with AWS D1.4 for manual welds.

E. Set wire ties, if used, with ends directed into concrete, not toward exposed concrete surfaces.

F. Reinforcing bars shall not be bent in the field.

G. Bars with bends and kinks not shown in the Agreement Drawings shall not be used. Do not straighten or rebend reinforcement.

3.4 PREPARATION FOR SEGMENT CASTING

A. Thoroughly clean and inspect molds before each use.

B. Coat molds with release agent that will not discolor or adversely affect the concrete before each use in accordance with manufacturer's recommendations. Do not allow the release agent to contact steel reinforcement or existing concrete surfaces.

C. Accurately place reinforcing steel. Use cages sufficiently rigid to prevent deformation during manufacturing process. Check reinforcement cages and other embedments within each mold prior to casting.

D. Fix concrete spacers or chairs so that the reinforcement is held firmly in the correct position within the formwork with all the cover as specified. The spacers or chairs shall be rigidly fixed to the reinforcement to prevent displacement. Do not use spacers in the circumferential or radial joint regions. The joint regions are the areas up to a distance of 0.5 inches from the joint surface.

E. Tie wire may not intrude into the minimum concrete cover of the segments. All wire ends shall be turned inward into the segment body.

F. Check reinforcement cages, plastic inserts, lifting socket, plugs, and other embedments are properly positioned to the specified tolerances and clearances with the required cover prior to each casting.

G. Maintain concrete batching and conveyance equipment in proper operating condition.

3.5 SEGMENT CASTING

A. Fabricate segments to dimensions and tolerances shown on the Agreement Drawings.

B. Segments shall be manufactured under cover in controlled conditions and protected against adverse weather, heat, cold and humidity.

C. Do not add water to concrete after adding high-range water-reducing admixtures to mixture.

D. Place concrete to avoid segregation of the materials and the displacement of the reinforcement.

E. Placement shall conform to ACI 301, ACI 304R, ACI 306.1, ACI 305.1, and ACI 309R.

F. Consolidate concrete in accordance with ACI 309R for complete contact with molds and embedded items. Consolidate concrete adjacent to side molds and along the entire length of molds to ensure a smooth surface finish. Use fixed vibratory motors firmly mounted to the underside of the segment mold to consolidate concrete into place. Do not use handheld ‘stinger’ type vibrators.

G. Finish the segment extrados surface by steel float, with only a minimum of surface working consistent with the requirement to achieve a smooth level uniform surface.

3.6 CURING

A. Cure all segments using either moist curing, curing compounds or curing at elevated temperatures, or a combination of these systems.

B. Cure segments and protect during storage in accordance with ACI 533.

C. Where used, steam cure at atmospheric pressure in accordance with ACI 517.

D. If steam curing is used:
   1. After the segments are cast, place the segment forms in an enclosure or chamber large enough to allow complete circulation of steam.
   2. Do not remove segments from forms until the required stripping strength is attained, as determined by test cylinders.

3. Reduce the amount of heat required for curing using a concrete maturity system in accordance with ASTM C1074.
4. Requirements for maximum chamber temperature, preset period, rate of heating and rate of cooling shall be set to secure favorable mechanical properties and durability and to minimize surface defects and cracking. These include:
   a. Preset period: 2-5 hrs, after initial set.
   b. Maximum chamber temperature during temperature rise phase: 140 ºF (60 ºC).
   c. Maximum rate of heating: 68 ºF/hr (assuming approximately 200 mm as maximum radius of steam curing).
   d. Temperature plateau phase: 1-3 hrs at 176º F (80 ºC) or 4-12 hours at 149 ºF (65 ºC).
   e. Maximum temperature in the concrete center: 176º F (80 ºC).
   f. Maximum rate of cooling: 68 ºF/hr.
5. Ensure that steam curing jets, where used, are not applied directly onto the concrete segments or segment molds.
6. Continuously monitor temperatures during curing.
7. Control cooling rate to limit temperature differential to avoid thermal cracking.
8. Demonstrate in pre-production and production testing that steam curing will not adversely affect the hardened concrete properties.

E. Following the initial curing period, apply a 90% efficient aluminized clear curing membrane in accordance with ASTM C309. Spray applications of a curing membrane shall be within one hour of removal of wet curing. The segment surface temperature during application of curing compound should not be more than atmospheric temperature + 68 ºF/hr. Application shall be at least the minimum coverage as recommended by the manufacturer.

3.7 DEMOLDING

A. Do not remove a segment from the mold until the concrete has achieved the stripping strength shown on the Agreement Drawings.

3.8 GASKET INSTALLATION

A. Prior to installation, store gaskets under cover in a dry storage area in an undeformed, relaxed condition at moderate temperatures and protected from direct sunlight. Protect gaskets from circulating air; do not store near equipment that can generate ozone (such as electric motors). Keep the gaskets clean, particularly avoiding contact with metals, solvents, oil, and grease. If cleaning of gaskets is necessary, use only cleaning materials and procedures recommended by the gasket manufacturer.

B. For glued gaskets, apply gasket adhesive to the segment and fit gasket onto the concrete surface of the segment in accordance with the manufacturer's instructions and recommendations. Remove any excess adhesive that covers the mating surface of the gaskets.

C. Inspect each completed segment for correct seating of the gasket frame and uniform adhesion prior to storage. Re-inspect the gasket prior to transport to site, segment transport into the tunnel, and segment erection.

3.9 DAMAGED SEGMENTS

A. Inspect the segments after demolding, and after delivery to site prior to loading into the tunnel.

B. Use the following classification system to record damage:

Table 8: Damage Classification System

			Repairs Required	
			Damage prior to installation in tunnel	**Damage after installation in tunnel**
CONCRETE SECTION DEFECTS	SC-1A	Crack starting from joint in longitudinal direction in-between thrust rams	Repair Type 1A	Repair Type 1B
	SC-1B	Crack starting from joint in longitudinal direction at thrust rams	Repair Type 1A	Repair Type 1B
	SC-1C	Crack starting from joint in longitudinal direction running through grout socket/shear pin recesses	Repair Type 1A	Repair Type 1B
	SC-1D	Crack starting from internal face of segment	Repair Type 1A	Repair Type 1B
	SC-1E	Crack starting from external face of segment	Repair Type 1A	N/A
	SC-2	Crack in circumferential direction	Repair Type 1A	Repair Type 1B
	SC-3A	Spalling at segment corner	Repair Type 2A	Repair Type 2B
	SC-3B	Spalling at segment edges (circumferential joint)	Repair Type 2A	Repair Type 2B
	SC-3C	Spalling at segment edges (radial joint)	Repair Type 2A	Repair Type 2B
	SC-3D	Damage to outer edge of circle joint	Repair Type 2A	Repair Type 3
	SC-3E	Damage around coupling elements: Shear dowels, bolt and dowel pockets, cam & pocket, tongue & groove.	Repair Type 2A	Repair Type 2B
	SC-4	Splitting-bursting cracks	N/A	As agreed with Designer
	SC-5	Key damage during placement	N/A	Repair Type 2B
	SC-6A	Spalling around shear cone recess or grout socket	Repair Type 2A	Repair Type 2B
	SC-6B	Grout socket pull-out	N/A	Repair Type 2B
	SC-7	Key movement	N/A	As agreed with Designer
	SC-8	Fire damage	Reject segment	As agreed with Designer
CONCRETE SURFACE DEFECTS	SU-1	Voids (bug holes)	Repair Type 2A	N/A
	SU-2	Exposed reinforcement	Repair Type 2A	Repair Type 2B
	SU-3	Exposed aggregates (honeycombing)	Repair Type 2A	N/A
	SU-4	Loss of concrete skin	Repair Type 2A	N/A
INSERT DAMAGE	ID-1	Grout or grease leakage into inserts	Repair Type 2A	N/A
	ID-2	Incorrect insert location	Repair Type 2A	N/A
GASKET DAMAGE	GD-1	Damage to gasket material	Replace gasket	Repair Type 1C
	GD-2	Detachment/Pull-out of gasket	As agreed with Designer	Repair Type 1C
	GD-3	Incorrect positioning of gasket	As agreed with Designer	Repair Type 1C
WATER LEAKAGE	WL-1A	Excessive gap between adjacent segments	N/A	Repair Type 1C
	WL-1B	Excessive offset between segments	N/A	Repair Type 1C
	WL-2	Leakage from joints/bolt holes	N/A	Repair Type 1C
	WL-3	Leakage from cracks	N/A	Repair Type 1C
	WL-4	Leakage from insert e.g. grout socket	N/A	Repair Type 1C
OTHER	O-1	Loose Bolts	N/A	Tighten to spec
	O-2	Other	As agreed with Designer	As agreed with Designer

C. Record results of inspections in Segment Tracking Database, including classification, dimensions and photographs of the damage.

D. Reject segments that have reached the following rejection criteria prior to erection in the tunnel lining:
1. A crack extending through a complete cross section of the segment.
2. Two or more cracks combined such that a wedge is formed that may separate from the segment.
3. Honeycombing other than minor surface defects.
4. Spalling to a depth in excess of 2 inches.
5. Spalling affecting gasket, dowel, bolt or guide rod seating or confinement.
6. Damage to gasket grooves in excess of 5 percent of the length along edge side of segment.
7. Cracks around lifting inserts, dowels or gasket groove.
8. Other damage or defects that in the opinion of the Designer could significantly impact the structural capacity of the segment, such as any cracks on bearing surfaces.
9. Segments not meeting tolerance requirements, minimum strength requirements or other requirements of this Section.

E. Indelibly mark rejected segments on the inner (concave) face with the word “DISCARD”, permanently remove from the work site, and do not use in the project.

3.10 REPAIR OF DEFECTS

A. Repair of Damaged Segments Before Installation: Repair the concrete segments before erection by removing defective/damaged areas to sound concrete and patching minor damage/defects using the repair types listed below, for items including but not limited to:
1. Blow holes and air voids.
2. Minor chipping and spalling.
3. Local protrusions.
4. Minor non-structural defects.

B. Repair of Damaged Segments After Installation: For damage not involving leakage, repair the concrete segments after erection by removing defective/damaged areas to sound concrete and repairing using the repair types listed below.

C. Repair Types:
1. Repair Type 1A: Seal crack(s) using epoxy injection if damage does not exceed rejection criteria.
2. Repair Type 1B: Seal crack(s) using epoxy injection if greater than 8 mil (0.2mm). For damage involving leakage, repair in accordance with Section 310179 “Sealing Leaks”.
3. Repair Type 1C: For damage involving leakage, repair in accordance with Section 310179 “Sealing Leaks”.
4. Repair Types 2 and 3 as follows:
    a. Sand cement mortar for less than 0.6 inches deep and 1.5 inches in width.
    b. Non-shrink epoxy repair mortar for areas greater than 0.6 inches deep and/or 1.5 inches in width.
5. Repair Type 2A: Repair if damage does not exceed rejection criteria.

6. Repair Type 2B: Repair if more than 5% of joint bearing surface or segment cross section is missing or damage extends to gasket groove. Repair, and then seal in accordance with Section 310179 “Sealing Leaks” if water inflow exceeds allowable local infiltration rate.
7. Repair Type 3: If possible, to do before next advance, repair edge if damage extends to gasket groove. If not, repair in accordance with Section 310179 “Sealing Leaks” if water inflow exceeds allowable local infiltration.

D. Repair segments in accordance with ACI 224.1R.

E. Record details of repairs in Segment Tracking Database, including materials used, date of repair, and photographs of the repaired area.

3.11 FIELD QUALITY CONTROL

A. At a minimum, include the following items in the Inspection and Test Plan:
1. Surveillance:
   a. Mold cleanliness after preparation.
   b. Proper application of release agent.
   c. Secure anchoring of form inserts and embedded items.
   d. Clear cover to reinforcement.
   e. Concrete placement and consolidation.
   f. Concrete surface finishing.
   g. Curing procedures.
   h. Concrete testing.
   i. Concrete sample collection.
2. Review:
   a. Prequalification plastic and hardened concrete test results.
   b. Mix development report.
   c. Concrete test results.
3. Verification:
   a. Temperature measurements during curing.
   b. Tolerances are within specified limits.
4. Witness Point:
   a. Laboratory mix development trials.
   b. Prequalification batching trials.
   c. Repair inspections.
   d. Repairs.
5. Hold Point:
   a. Precast facility readiness for production casting.
   b. Reinforcing steel and embedments properly placed in mold.

B. Concrete Tests: Testing of composite samples of fresh concrete obtained according to ASTM C172 shall be performed according to the following requirements and as summarized in Table 10:
1. Perform all production concrete testing with in-house testing laboratory, or by Independent Testing Agency.
2. Prepare a minimum of nine cylinders and cure per ASTM C31 for each 24 hour production period or for every 120 cubic yards of concrete used, whichever is more frequent. Take at least three cylinders from each casting cycle. Test cylinders may be either 6 inch by 12 inch concrete or 4 inch by 8 inch.

3. Testing Frequency: Obtain one composite sample for each 50 cubic yard.
4. Slump: ASTM C143; one test at point of placement for each composite sample, but not less than one test for each day's pour of each concrete mixture. Perform additional tests when concrete consistency appears to change. Concrete that has been rejected for failing to meet the slump requirements shall not be used.
5. Air Content: ASTM C138 gravity method, or ASTM C231 pressure method, for normal-weight concrete; one test for each composite sample, but not less than one test for each day's pour of each concrete mixture.
6. Concrete Temperature: ASTM C1064; one test hourly when air temperature is 40 deg F and below or 80 deg F and above, and one test for each composite sample.
7. Test cylinders for compressive strength as follows: three cylinders after 7 days, three cylinders at 28 days, and the remaining cylinders after 56 days per ASTM C39.
8. Strength of each concrete mixture will be satisfactory if every average of any three consecutive compressive-strength tests equals or exceeds specified compressive strength and no compressive-strength test value falls below specified compressive strength by more than 500 psi.
9. At weekly intervals during segment manufacture, prepare two cylinders from the same concrete batch and cure in same manner as segments; demonstrate that minimum strength for demolding as shown on the Agreement Drawings is being attained before it occurs. If average strength of two cylinders is less than specified on the Agreement Drawings, modify procedures to demonstrate the minimum cured strength is met.
10. Strength of each concrete mixture will be satisfactory if every average of any three consecutive compressive-strength tests equals or exceeds specified compressive strength and no compressive-strength test value falls below specified compressive strength by more than 500 psi.
11. Test results shall be reported in writing to within 48 hours of testing. Reports of compressive-strength tests shall contain project identification name and number, date of concrete placement, name of concrete testing and inspecting agency, location of concrete batch in work, design compressive strength, concrete mixture proportions and materials, compressive breaking strength, and type of break for 7, 28 and 56-day tests.
12. Perform two of each of the following tests each month on samples without fibers:
    a. The hydraulic conductivity tests on the concrete, in accordance with CRD-C 48.
    b. Chloride ion penetrability to ASTM C1202.
13. Perform three Non-Steady-State Migration Experiment tests, in accordance with Nordtest 492, on minimum 28-day old samples during the course of the project at monthly intervals.
14. Specimens used for determination of chloride migration coef. shall not include steel fibers or any metallic residues.
15. Measure the concrete cover over reinforcement using electromagnetic cover meter or GPR equipment in both extrados and intrados surfaces at a 10-inch grid spacing. Perform measurements during the course of the project at a frequency of 1 segment per month.
16. During the course of the project at equal intervals, perform two accelerated carbonation tests to fib-34 clause B.1.2.5.2 using 4inch x 4inch x 16inch prisms with a total test duration $\Delta t_{curing(7d)} + \Delta_{tlab(21d)} + \Delta t_{ACC(28d)} = 56$ days at 2% CO_2 concentration for 28 days.
17. For fiber-reinforced concrete, for every 5 days of production or 650 cubic yards of concrete, whichever the more frequent:
    a. Cast a minimum of seven beams for residual flexural testing and perform tests in accordance with this Section. Test one beam at 14 day age, test three at 28 day age and three at 56 day age.
    b. Conformity of residual strength is obtained when:

1) The mean value of test results obtained from 3 test specimens fulfils the requirement for the specified residual strength in Table 4 up to the deflection limit.
2) Individual test results at any point corresponding to the specified deformation level show a residual stress that is no lower than 90% of the stress corresponding to the specified strength class.

c. Cast a minimum of four (4) 12inch H x 6inch diameter cylinders for Double Punch Loading Testing (DPT) and perform tensile splitting tests in accordance with this Section. Cut cured cylinders in half to make samples for DPT testing. Test four (4) cylindrical samples at 14 days and four (4) samples 28 days. Perform testing per the draft ASTM WK73384 method.
d. At the discretion of the Designer, the frequency and number of testing may be relaxed following 60 days of production demonstrating consistent results.

18. For fiber-reinforced concrete, perform washouts tests to verify the fiber content and distribution. Sample and test in conformance with Canadian Standards Association A23.2 modified as follows:
    a. The washout test shall be performed on a minimum 0.5 cubic foot sample from of every 30 cubic yards of concrete.
    b. Samples of concrete may be taken from a single batch and shall be obtained at two separate times of discharge for each batch of concrete used, one near the start of pouring and the second near the end of pouring. Samples shall be remixed and tested as a single sample.
    c. Prior to performing each washout test, weigh the empty sample container and the container filled with the concrete sample. Determine the weight of the concrete sample by subtracting the weight of the empty sample container from the filled container. The sample container shall maintain a known and measured volume for the washout test.
    d. Use a vibrating table to consolidate the sample and screed off the top of the sample to obtain the same volume for each sample taken. Use the weight and the known volume of the sample to obtain a unit density.
    e. Wet sieve the sample through three screens of decreasing size (1 1/4 inches, 3/4 inch, and 1/4 inch) by spraying with water. Use a magnet to remove the steel fibers from each of the 3 screens.
    f. The weights of the empty container, concrete samples, and the dried fibers for each washout test sample shall be recorded using a scale having an accuracy of 0.005 oz. Measure the volume to the nearest 0.5 oz.
    g. The fiber distribution testing must meet the following:
        1) The average fiber content from a set of three samples must be greater than 95%, but less than 115% of the mix design content.
        2) No individual sample has a minimum fiber content of 80% and a maximum of 130% of the mix design content for each sample.
    h. If washout tests indicate insufficient fiber dosage, propose remedial actions to demonstrate adequate dosage amounts or additional testing to verify the adequacy of the concrete for incorporation into the works.
    i. At the discretion of the Designer, the frequency of washout testing may be relaxed following 30 days of production demonstrating consistent dosage amounts.
19. Nondestructive Testing: Impact hammer, sonoscope, or other nondestructive device may be permitted by Company but will not be used as sole basis for approval or rejection of concrete.

20. Additional Tests: Perform additional tests of concrete when test results indicate that slump, air entrainment, compressive strengths, or other requirements have not been met, as agreed by Company.
21. Perform additional testing and inspecting to determine compliance of repaired segments with specified requirements, as agreed by the Company.
22. Correct deficiencies in the work that test reports and inspections indicate do not comply with the Agreement and Exhibits.

C. Independent Testing:
1. If an in-house testing laboratory is utilized to perform the preproduction and/or production testing, for auditing and independent testing purposes engage an Independent Testing Agency experienced with the sampling and testing of concrete.
2. Twice during mix development, coordinate with Independent Testing Agency to visit the batching plant(s) to witness stages of preproduction mix development, including at a minimum, laboratory batching, sampling and sample preparation, and final batching plant trials.
3. Once per month during production, coordinate with Independent Testing Agency to visit the batching plant(s) and/or to witness stages of production, including at a minimum, concrete batching, sampling and sample preparation. Independent Testing Agency to perform full suite of tests specified of fresh concrete (slump, temperature, etc.), and to prepare test samples and replicate the daily and monthly in-house testing regime, and identify if there are any discrepancies in the test results outside of standard statistical variations.
4. If the tests performed by Independent Testing Agency identify discrepancies, meet with Company to identify the reasons and implement any corrective actions needed.

D. Mold and Segment Geometry:
1. Mold Dimensions:
    a. Use a 3-dimensional laser tracker, or similar system approved by the Designer. Together with any other methods to confirm that the dimensions of the molds are in accordance with those needed to meet the specified segment tolerances.
    b. Fully check the molds for dimensional accuracy (angles, distances and torsion) prior to and throughout the segment production process using 3-dimensional laser tracking.
    c. For molds subject to internal/ external vibration, verify the 3-dimensional accuracy of each mold at initial factory installation and after each 200 uses.
2. Segment Dimensions:
    a. Implement a tolerance measuring system to account and adjust for thermal, moisture, and ambient temperature influences.
    b. Fully check the segments for dimensional accuracy (angles, distances and torsion) against the tolerances shown on the Agreement Drawings prior to and throughout the segment production process using 3-dimensional laser tracking.
    c. The 3-dimensional accuracy of each segment shall be verified after:
        1) initial use of each mold.
        2) first 5 uses.
        3) first 50 uses.
        4) after each 100 subsequent uses.
    d. If any measurement of any segment is found to be out of tolerance:
        1) Indelibly mark the segment with the word “DISCARD” and discard the segment.

2) Measure the previous 25 segments produced from that specific mold for compliance with required tolerances. If any segments are found to be out of tolerance, indelibly mark the segment with the word "DISCARD" and discard the segment.
3) If any measurement of the previous 25 segments is found to be out of tolerance, repeat the process of discarding the defective segment and measuring the next 25 previous segments until no defective segments are discovered. At that point, use the segments to build a new trial ring on top of the base ring to confirm trial ring tolerances can be met.

e. Provide any necessary resources to facilitate independent testing and inspections by the Company and the Designer, including gages, and calipers adequate to determine accuracy and tolerances in manufacture.
f. Keep a record of all the units cast in each mold. Withdraw from service any mold that becomes distorted or that casts faulty units until it is proved to be corrected.

3. Trial Rings:
a. Prior to beginning full production of precast concrete segments, erect a demonstration section. The section shall comprise two complete precast concrete segment trial rings, without gaskets or packings, but with all other appurtenances including dowels (modified to allow disassembly as required), bolts and alignment rods.
b. Build the trial rings on a flat level base, one above the other and rotationally offset by one or more clock positions.
c. Check the dimensions listed in Table 9 against the corresponding tolerances on each ring of the demonstration section.

Table 9: Trial Ring Tolerances

Item to be checked	Tolerance
Inside diameter (ID) measured at four evenly spaced locations around the ring	0.25 inches maximum
Lip between adjacent segments on inside diameter	0.06 inches maximum
Gap between joints with bolts tight and no packing	0.02 inches maximum (feeler gauge not passing).
Bolt holes	All bolt holes aligned such that the bolts can be inserted and fully tightened.

d. If the trial rings do not meet tolerances, manufacturing adjustments shall be made as necessary and the trial ring assembly repeated. Full production of segments shall commence only after successful completion of the demonstration lining trial assembly.
e. Retain the base ring of the demonstration section as a master ring for the duration of casting. Every 250 rings, perform either of the following checks to confirm segments from the current production meet the trial ring criteria:
1) Add a new top ring to the master ring and check the required dimensions, or
2) Use software to check a virtual ring based on the 3-dimensional laser tracker measurements. If this approach is adopted, then the accuracy of the software for checking the virtual ring should be demonstrated on the initial trial ring and approved by the Company.
f. If the trial rings do not meet tolerances, stop using the associated molds until manufacturing tolerances have been adjusted as necessary and a new trial ring assembly meets the required tolerances.

Table 10: Sampling, Testing, and Acceptance Requirements

Material or Product (Subsection)	Type of Acceptance (Subsection)	Characteristic	Test Method Specification	Sampling Frequency	Point of Sampling	Split Sample	Reporting Time	Remarks
Source								
Aggregate	Measured and tested for conformance	Quality	Subsections 2.2 and 3.1	1 per material type	Source of material	If requested	Before producing	–
Mix Design								
Concrete composition	Measured and tested for conformance	All	Subsections 2.3 and 3.1	1 per mix design	"	If requested	"	–
Production Start-up								
Strength and post cracking strength of fiber reinforced concrete		Compressive strength [b] [c] Flexural strength and residual flexural strength [d] Double punch loading test [e]	ASTM C31, ASTM C39 BS EN 14651 ASTM WK73384 [e]	1 set per mix design	Discharge stream at point of placement	If requested	Upon completing tests	–
Durability	Measured and tested for conformance [a]	Air void system [f] Freezing and Thawing resistance [g] Maximum chloride permeability [h] Maximum chloride migration coef. [i] Drying shrinkage [j] Water permeability [k] Carbonation resistance [l]	ASTM C457 ASTM C666 ASTM C1202 NT Build 492 ASTM C157 CRD C48 *fib* method	1 set per mix design	Discharge stream at point of placement	If requested	Upon completing tests	–
Production								
Produced aggregate (fine & coarse)	Measured and tested for conformance	Gradation Fineness modulus Moisture test	MTM 109 MTM 109 AASHTO T 255 / ASTM C566	1 per day – –	Flowing aggregate stream (bin, belt, discharge conveyor belt, or stockpile)	Yes	Before batching	–

Table 10 (continued): Sampling, Testing, and Acceptance Requirements

Material or Product (Subsection)	Type of Acceptance (Subsection)	Characteristic	Test Method Specification	Sampling Frequency	Point of Sampling	Split Sample	Reporting Time	Remarks
Production (continued)								
Concrete	Measured and tested for conformance	Density Air content Slump Temperature Fiber content	ASTM C138 ASTM C138 or C231 ASTM C143 ASTM C1064 CSA A23.2	See 3.11B	Point of discharge	No	Upon completing tests	–
Concrete	Statistical	Compressive strength[b][c] (28/56-day or otherwise stated in plans)	ASTM C31, ASTM C39	1 set per 120 yd^3, but not less than 1 per day	Discharge stream at point of placing	Yes	7/28/56 days	Deliver verification cylinders to designated laboratory for sched-uled testing
				Two cylinders per week			Prior to demolding	
Strength and post cracking strength of fiber reinforced concrete	Measured and tested for conformance	Flexural strength and residual flexural strength [m] Double punch load-ing test	BS EN 14651 ASTM WK73384 [e]	1 set of beams and cylinders per 650 yd^3	Discharge stream at point of placement	If requested	7/28/56 days	–
Durability	Measured and tested for conformance [a]	Maximum chloride permeability [h] Maximum chloride migration coef. [i] Water permeability [k] Carbonation re-sistance [l]	ASTM C1202 NT Build 492 CRD C48 *fib* method	1 set per 650 yd^3 1 set per 650 yd^3 2 tests per month 3 tests over project duration	Batching plant prior to addition of fibers	If requested	Upon com-pleting tests	–

Notes to Table 10

(a) Sample according to AASHTO R 60, except composite samples are not required.

(b) Cast at least nine compressive strength test cylinders for 6- by 12-inch (150- by 300-millimeter) specimens or 4- by 8-inch (100- by 200-millimeter) and carefully transport the cylinders to the job site curing facility.

(c) A single compressive strength test result is the average result from two 6- by 12-inch (150- by 300-millimeter) or three 4- by 8-inch (100- by 200-millimeter) cylinders cast from the same load.

(d) Materials approval associated with residual flexural tensile strength requirements shall be based on the results of 12 beam specimens tested in accordance with BS EN 14651 and characteristic values calculated assuming a normal distribution.

(e) Currently in draft form awaiting ASTM approval.

(f) The test sample used for the microscopic air-void analysis shall be obtained from coring therefore representing the finished element. The concrete mix design information shall include one microscopic air-void analysis performed by a testing laboratory in order to determine the spacing factor of the hardened concrete. If adjustments to the mix design are necessary, the air void analysis shall be repeated. An air-void spacing factor shall be determined in accordance with ASTM C457 modified point count method at 100 times magnification.

(g) Satisfactory freeze-thaw durability shall be substantiated by proper air-entrainment or demonstration that the durability factor is achieved. Preconstruction testing shall be conducted to demonstrate that the concrete is resistant to freezing and thawing on at least 3 samples in accordance with ASTM C666/C666M.

(h) Cast at least three 4- by 8-inch (100- by 200-millimeter) maximum chloride permeability cylinders per set and carefully transport the cylinders to the job site curing facility. Cure the cylinders for 7 days according to ASTM C31. Then cure at 100 °F ± 10 °F (38 °C ± 5 °C) in saturated lime water until ASTM C1202 sample conditioning begins. Have the testing done at 28 days in a testing laboratory. The set test result is the average of the measurements on three cylinders cast from the same load. Adjust production test result by the average difference. Report both initial and adjusted test result.

(i) Cast at least three cylinders per set for determination of chloride migration coefficient in accordance with NT Build 492. Test samples at 28 days of age.

(j) If testing is required, use 3- by 3- by 11-inch (75- by 75- by 275-millimeter) prisms for drying shrinkage specimens. Cast at least three drying shrinkage prisms per set and carefully transport the prisms to the job site curing facility. Moist the prisms for the duration of the specified moist curing period. Have the testing done in a testing laboratory. The zero measurement for percent drying shrinkage is the initial measurement taken at demolding of the specimens at 23½±½ hours after introduction of mixing water to the concrete mixture. Measure percent drying shrinkage at the end of specified moist curing period for the structural elements, 1, 4, 7, 14, 28, and 56 days after the end of the specified field moist curing period. Drying shrinkage 28 days after the termination of moist curing (28 days drying) cannot exceed 60 percent of the maximum specified value. The set drying shrinkage test result is the average result from three prisms cast from the same load.

(k) The depth of water penetration into the concrete (permeability) shall be measured on samples of concrete following appropriate procedures described in CRD C-48. At least three samples shall be cored. No passage of water through samples shall be visible when exposed to a vertical water head equal to 200 psi (460 foot head pressure) for 14 days.

(l) The resistance against carbonation of the concrete shall be measured on samples of concrete following the appropriate procedures described in fib bulletin 34, section B.1.2.5.2. A minimum of two prism specimens with dimensions 4 in. (100 mm) in width, 4 in. (100 mm) depth and 19.7 in. (500 mm) in length. Total test duration is 56-days; including 7-days water curing and 21 days air drying in standardized laboratory climate; shall be placed in a carbonation chamber with a CO2 concentration of Cs = 2.0 vol% during 28 days.

(m) Conformity of residual strength is obtained when: 1) the mean value of test results obtained from 3 test specimens fulfils the requirement for the specified residual strength up to the deflection limit; 2) individual test result shall in any point (corresponding to the specified deformation level) show a residual stress that is lower than 10 % of the stress corresponding to the specified strength class.

(n) If three successive samples are tested and compliance to the specifications is indicated, screening tests may be reduced to an approved frequency. Resume initial testing frequency if a test shows a failing temperature, air content, slump, or when directed.

(o) If the point of placement is different from the point of discharge, correlate the discharge tests with the placement tests to document the changes.

END OF SECTION 317416

SECTION 317119 – EXCAVATION BY TUNNEL BORING MACHINE

PART 1 - GENERAL

1.1 SUMMARY

A. Section includes conducting all work necessary to complete the Straits Tunnel with the use of a pressurized face Tunnel Boring Machine (TBM). Elements of work include, but are not limited to, the following:
   1. Providing TBM capable of excavating and supporting the ground in all conditions encountered.
   2. Design of the total TBM system, all backup equipment, auxiliary systems, support equipment, and other items necessary for the sustained operation of the TBM including the Slurry Treatment Plant (STP) and slurry circuit, water treatment and disposal systems, maintaining a positive face pressure, and maintaining face stability to meet the requirements of this project and all regulatory requirements.
   3. Furnishing and installing the permanent precast concrete tunnel lining (PCTL) consisting of gasketed precast concrete segments.
   4. Excavating, transporting, and disposing of excavated materials.
   5. Furnishing shield gap injection system capable of continuously injecting a viscous filler in the annular gap between the shield extrados and the excavated surface to support the ground until backfill grout is provided immediately behind the tail shield.
   6. Furnishing and placing backfill grout continuously and immediately behind the tail shield to ensure the annular gap between the PCTL extrados and excavated surface is completely filled concurrently with the TBM advance.
   7. Designing, furnishing and using slurries, conditioners, polymers, bentonite and/or other conditioning agents (all referred to herein as conditioners) at all times and of the types required to maintain face stability, reduce wear, advance the heading, and transport spoils in these ground conditions with the TBM and equipment selected.
   8. Performing interventions as required within the TBM working chamber for tool changes, maintenance, or repairs.
   9. Installing and maintaining construction drainage, lighting, power, water, fire line, compressed air and ventilation, temporary communication, verbal, Wi-Fi/internet.
   10. Installing and maintaining Tunneling Monitoring and Documentation System.
   11. TBM assembly, launch, and recovery.
   12. Drilling probe holes and grouting from tunnel face and around the shield perimeter with preventer and blow off valves to resist water and material ingress.

B. Related Requirements:
   1. Section 023200 “Geotechnical Investigations”.
   2. Section 310179 “Sealing Leaks” for sealing the PCTL if water leakage exceeds the specified leakage criteria.
   3. Section 310913 “Geotechnical Instrumentation and Monitoring” for installing and collecting and analyzing data from geotechnical instruments.
   4. Section 312320 “Water Treatment and Disposal”.

5. Section 312326 "Reuse and Disposal of Excavated Materials" for requirements for handling, transportation and disposal of material generated by excavation for the tunnel using the Tunnel Boring Machine (TBM).
6. Section 317117 “Backfill Grouting” for performing backfill grouting and check grouting during tunneling.
7. Section 317416 "Precast Concrete Tunnel Lining" for manufacturing, handling, transporting and installing gasketed PCTL segments.

1.2 DEFINITIONS

A. Tunnel Boring Machine (TBM): A tunneling machine, which provides full excavation face support. TBM refers to the total system of tunnel boring equipment, including auxiliary and support equipment comprising the TBM, backup gear and all fixed equipment necessary for the successful operation of the machine.

B. Slurry TBM: A closed face TBM able to provide ground support with a pressurized face and excavation chamber and working chamber (separated with submerged wall) with a fluid mix containing particles of excavated ground in bentonite slurry or water acting as the face support medium. A pressurized slurry circuit is used to convey the excavated material to the Slurry Treatment Plant.

C. Variable Density TBM (VDM): A modified version of a Slurry TBM that can accommodate a wide range of viscosity, shear strength and density of the face support medium in the pressurized face. The VDM will typically remove material from the pressurized face using a screw conveyor, then passing through a crusher, as part of a pressurized slurry circuit.

D. Earth Pressure Balance (EPB): A TBM with a pressure bulkhead located behind the face to form a plenum under pressure. Liquids and conditioners are injected into the tunnel face and the plenum to be mixed with material excavated by the rotating cutterhead and form the face support medium. The mix is extracted by means of a screw mechanism in an operation integrated with the TBM advance. The VDM may be operated in EPB excavation mode but with slurry transportation mode behind a slurrifier box.

E. Apparent Density: Estimated density of excavated material based on calculations using face support medium density and volume measurements before and after the face support medium passes through the TBM.

F. Clay Shock Filler: Clay Shock is high viscosity plasticized material, which is generated by mixing with a special clay-sand material (TAC-Beta® or material with similar properties) and sodium silicate. The material can be injected into voids around the TBM using pressurized injection ports in the shield and/or tail skin while maintaining injection of backfill grout around the PCTL. The Clay Shock high viscosity means it can fill large voids underground aiding in ground stability while reducing frictional resistance. Clay Shock does not harden in the long term while maintaining its material properties (viscosity, permeability, strength, etc.). The viscosity is programmable over a wide range from 0.1 to 20 lbs-s/ft^2 (50 to 1000 dPa−s).

G. High Viscosity Bentonite Support: Face support medium (slurry/bentonite) with high shear strength/viscosity to be able to create filtercake/membrane in ground conditions with high permeability to ensure slurry losses are minimized in such conditions and applicable for Slurry or VD TBM Type.

H. High Density Slurry Support: Face support medium (slurry) with a higher density than the usual bentonite density, used to allow face pressure application without heave or blowout in areas with shallow overburden and low rock cover under lakebed. It is applicable to both Slurry TBMs and VDMs.

I. Key Restraint System: Set of engineering components designed to be bolted to the key segment and the previous ring to provide restraint against key movement.

J. Refuge Chamber: A refuge chamber is a place of temporary safety for personnel to be installed on the TBM in the case of an incident.

K. Squeezing Ground Conditions: Ground convergence resulting in the ground coming in contact with the TBM.

1.3 REFERENCES

A. American Society of Mechanical Engineers (ASME):
   1. ASME PVHO-1: Safety Standard for Pressure Vessels for Human Occupancy.

B. ASTM International (ASTM):
   1. ASTM D2435 Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading.
   2. ASTM D4318 Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.
   3. ASTM D4767 Standard Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils.
   4. ASTM D6913 Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis.

C. British Tunnel Society (BTS):
   1. A Guide to Work in Compressed Air.

D. Environmental Protection Agency (EPA) Environmental Sampling and Analytical Methods Program:
   1. EPA Method 300.1 Determination of Inorganic Anions in Drinking Water by Ion Chromatography.
   2. EPA Method 310.2 Alkalinity (Colorimetric, Automated, Methyl Orange) by Autoanalyzer.
   3. EPA Method 350.1 Determination of Ammonia Nitrogen by Semi-Automated Colorimetry.
   4. EPA Method 415.3 Determination of Total Organic Carbon and Specific UV Absorbance at 254 nm in Source Water and Drinking Water.
   5. EPA Method 1601 Male-specific (F+) and somatic coliphage in water by two-step enrichment procedure.
   6. EPA Method 6010 Inductively Coupled Plasma - Atomic Emission Spectrometry.
   7. EPA Method 8015 Nonhalogenated Organics Using GC/FID.
   8. EPA Method 8260 Volatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS).

E. European Standard (Euronorm, EN):

1. EN 12110 “Tunnelling Machines, Air Locks, Safety requirements”.
2. EN 16191 “Tunnelling Machines - Safety requirements”.

F. European Association for Producers and Applicators of Specialist Building Products (EFNARC):
1. EFNARC Specification and Guidelines for the use of Specialist Products for Mechanical Tunneling in Soft Ground and Hard Rock.

G. International Tunneling Association (ITA-AITES):
1. Guidelines for Good Working Practice in High Pressure Compressed Air.

H. US Department of Labor-Occupational Safety and Health Administration:
1. 29 CFR 1926 Safety and Health Regulation for Construction.

1.4 PRECONSTRUCTION MEETINGS

A. The TBM and STP manufacturers shall review the STP and spoil transport system and ensure that the systems are compatible with the TBM design. After the TBM and STP design is submitted for review, organize a joint presentation by the TBM manufacturer and STP supplier prior to the approval of the Company. The presentation is to include the key provisions, features of the tunneling and STP system and performance criteria.

B. During TBM design development arrange, chair and provide meeting minutes for bi-weekly design meetings with the Company and the Designer.

C. During TBM manufacturing arrange, chair and provide meeting minutes for monthly progress meetings with the Company and the Designer.

1.5 ACTION SUBMITTALS

A. Product Data:
1. Gasket lubricant.
2. Tail skin grease.
3. Main bearing grease.
4. Hydraulic oils.
5. Viscous Clay Shock Filler.
6. Conditioner/polymer (if used).
7. Bentonite and bentonite fillers.

B. TBM Design Documents: Submit a description of proposed TBM including backup equipment within 60 days after Notice to Proceed. Provide sufficient details to demonstrate that the TBM meets specifications. Provide a detailed narrative demonstrating the suitability of the TBM and backup for tunneling in the ground conditions described in the Geotechnical Baseline Report (GBR), including:
1. General Arrangement Drawings from TBM manufacturer showing details of TBM including detailed scale drawings with sufficient vertical and horizontal sections at tunnel axis and cross sections to clearly identify the different components of the TBM and demonstrate that all requirements of this Section are met.
2. Provide a graphic and animation of TBM suitable for Company's use for public communications. The graphic and animation shall show the main features of the TBM

(cutterhead, operational modes, PCTL erection) but does not need to be an exact representation.

3. Details of the cutterhead, shield (length, thickness and taper) and slurry/muck treatment and transport system onboard the TBM, including the cutterhead diameter, layout and percent of face opening, cutters, drag bits, gauge cutters, overcut, center cutter, cutterhead wear plating, protection and wear detection system (as applicable), crusher details, wear plating, and slurry transport system. Include a preventative wear and replacement plan for excavation tools (of all types), elements of muck transport system as applicable and tail seals.
4. Details of integrated support pressure control system, pressure cells, face support medium density and volume measurement system, flow measurement system and bentonite and water injection systems.
5. Muck extraction and removal system with calculation of slurry flow rates and basis for TBM excavation management system. Include details of the two (minimum) methods (inclusive of operation description) to be used to measure the volume and density of excavated material.
6. Details of the drive and steering system including thrust cylinders, articulation cylinders and sealing system, main bearing and seals, tail seals, lube system, TBM guidance system, TBM torque calculation, anti-roll device details, hydraulic system schematic, and TBM shield gap injection system. Include details of the total thrust force. Include a description of the scheme for replacement of the cutterhead main bearing and cutterhead seals from within the tunnel.
7. Details of the shield including plate thickness, weld requirements, material grade and the results of calculations including but not limited to maximum hydrostatic pressure together with ground load and squeezing ground conditions. Define the maximum predicted oval deformation on the radius.
8. Details of the TBM management and safety systems, including the communication system (with internet Wi-Fi in TBM and Tunnel), data acquisition system, schematic electrical system, ventilation system, lighting system, personnel transportation system, water management pumps, compressed air locks and related equipment, gas monitoring system(s) (connected to surface alarm system) and fire suppression system.
9. System for cutterhead access and maintenance, including provisions for personnel and equipment lock for use when entering working chamber under compressed air, compressed air locks (applicable only if permanent airlock for bounce interventions is installed in addition to provisions for hyperbaric interventions), the ventilation system of the working chamber, cutter changing tools, and provisions for drilling probe holes through cutterhead and forward shield.
10. TBM shield supplemental bentonite injection system.
11. Details of contingency system for injection of viscous Clay Shock in the radial gap between the TBM shield and the ground excavated surface in the case of squeezing ground conditions.
12. Details of the segment erection and assembly and backfill system including the ring position selection system software, the description of segment erector and the interface of TBM with the PCTL elements, backfill grouting system (grout mixers, pressures and flow rates) including how these are calculated and reported, tail skin brushes and grease injection system, the segment erector, segment feeder and segment unloading onto the TBM. Include calculations to show that the TBM will be able to negotiate the horizontal and vertical tunnel alignment with sufficient clearance between the TBM tail skin and the extrados of the PCTL rings without causing damage to the PCTL. Include details of segment dismantling capability after ring erection.

13. Details of the refuge chamber with demonstration of capacity and survival duration factored into the design, accounting for tunnel length and emergency transport time.
14. Alignment control, guidance system and data acquisition system (including sample display screens).
15. TBM operator console and controls.
16. Probe hole drilling system, including location and number of ports, means to drill the probe hole ahead of the TBM, and the means to drill through the cutterhead and around the circumference of the TBM.
17. Any other systems or components required for the operation, maintenance, and reliability of the TBM.
18. Schematic of the TBM assembly sequence.
19. Schedule for the design and fabrication of the TBM, indicating procurement and supply of key components and materials, stages of fabrication and testing.
20. TBM Transport Route Study.

C. Slurry Treatment Plant (STP): Submit a description of the proposed STP within 60 days after Notice to Proceed. Provide sufficient details to demonstrate that the STP meets the requirements of this Section. Provide a detailed narrative demonstrating the suitability of the STP for the ground conditions described in the GBR, including:
   1. General arrangement drawings showing the complete STP design including the details of slurry pumps, pipelines, bentonite storage tanks, settling tanks, filters, screens, process control board, etc.
   2. Clearly demonstrate in the design the functionality and performance of the STP including but not limited to the following:
      a. How the STP will be operated and controlled in conjunction with the TBM as one integrated system.
      b. How the planned efficiency of separation of each stage (e.g. primary, secondary, fines) of the separation process is considered and show the particle size grade separation at each stage. This shall be specified in terms of weight of dry material processed per hour and the plant operational efficiency, based on past experience and not be taken as 100%.
      c. How the STP complies with the requirements for noise, dust and vibration.
   3. Within 120 days after Notice to Proceed provide manufacturer's specifications for each type and size of separation equipment and a STP operation & maintenance manual which shall be specific to the plant proposed at site. This manual shall include details on the monitoring and controlling of the slurry density, pH, rheology, sand content and viscosity to ensure optimum face confinement, transportation and separation characteristics.
   4. Two months prior to the commencement of tunneling a testing regime identifying test types, frequency of testing, location of testing, acceptable test value ranges and actions for correction for all aspects of the slurry tunneling operation shall be provided to the Company for acceptance. The testing regime shall ensure that the STP operators have sufficient information to allow real-time management of the STP and can make an effective assessment of the actual solid removal rate being achieved. The testing frequency shall reflect both consistent ground conditions and variable ground conditions but be no less than 3 times per shift.

D. PCTL Key Restraint System:
   1. As applicable, shop drawings stamped by a Registered Professional Engineer licensed in the State of Michigan.

E. Work Plans:

1. Provide an Initial Work Plan within 60 days of NTP, including the contents listed in Table 1 below.
2. Provide a Detailed Work Plan 30 days prior to the start of TBM assembly, adding more detail to the Initial Work Plan, including the contents listed in Table 1 below. If required, the holing through into the North Straits Shaft and TBM dismantling details with Section 4 of the work plan can be omitted from the first submittal and included in a revised submittal provided 30 days prior to the holing through.

Table 1: Work Plan Details

Work Plan Section	Initial Work Plan	Detailed Work Plan
1. General TBM Operation	• Overall supervisory staff organization and site responsibilities for each position supporting TBM operations both above and below ground. • Outline of Emergency Preparedness Plan. • Proposed TBM operation modes. • Tunnel logistics and supply of material. • Service pipe layout and extension. • Slurry pipe extension. • In-tunnel resources to be utilized, such as multipurpose service vehicles. • Program for fire prevention and mitigation. • Means and methods for drilling probe holes and for checking for hazardous and explosive gases. • Spill response plan.	Information in initial work plan, plus: • Detailed Emergency Preparedness Plan. • Details of the gas detection system, its equipment interlocks, alarms, set points, and operating logic network diagram. Also provide description of calibration data for gas detection instruments and procedures for operation. • Details of logistics for material and personnel supply to the TBM. • Details of the tunnel ventilation system. • Procedures for planned stoppages such as weekends and holidays to prevent loss of face stability and ground loss. Include description of measures to ensure attainment of target face pressure immediately at recommencement of excavation. • Procedures for extension of TBM high voltage supply cables, pipes and other utilities and ventilation as the TBM progresses. • Management plan for control of ground movement.
2. Spoil Management	• Details of slurry / muck transportation system through tunnels to Slurry Treatment Plant (STP). • Details of muck transportation from STP to disposal location. • Assembly of the STP.	Information in initial work plan, plus: • Details of the types of conditioners to be used, mixing methods, proposed muck to conditioner ratios and quality control (QC) program. A description of site conditions in which they will be used and the logic to be used in determining when, which, and how much to add; and the QC tests to be used in the field including a description of those tests and the range of values considered acceptable for ground conditions anticipated.

Work Plan Section	Initial Work Plan	Detailed Work Plan
		• Laboratory testing program for face support medium in slurry excavation mode (density and viscosity of bentonite or water/rock fine suspension). • Permits for disposing of excavated material, including contaminated materials, dewatering fluids, and tunnel drainage. • Method of assembly, operation and maintenance of STP and slurry circuit. • Material Safety Data Sheets (MSDS) for conditioners/admixtures. • Work plan for disposing of excavated material, bentonite, conditioners, dewatering fluids, and tunnel drainage.
3. Face Stability	• Design concept for TBM face pressure and other key operational parameters. • Conceptual design assumptions for tunneling key performance indicators (KPIs) including face stability, maximum allowable water inflow and potential highly permeable area. • Method of calculating required face pressure to maintain face stability for each reach and rock type, including acceptable operating tolerances, based upon the tunnel profile and anticipated ground and groundwater conditions. As a minimum for areas without water pressure, face pressures measured and corrected for tunnel axis depth shall be continuously maintained above that represented by a full working chamber or 0.8 Bar, whichever is higher, while turning the cutterhead (dynamic mode). • Method of monitoring the face pressure. • Work plan describing the intended TBM parameters to achieve the required face pressure balance pressure at the	Information in initial work plan, plus: • Details of special precautions and the inspection procedures to be taken when stopping the TBM for repair, weekends, holidays, and other scheduled stoppages to ensure that face stability is maintained during the shutdown, including contingency measures to be implemented if problems in ground or groundwater control develop or power is lost. • Calibration methods for pressure cells in excavation chamber and screw conveyor and for density and flow meters in shield section. • Methods for monitoring the rate at which material is excavated and removed from the face. • Planned minimum and maximum face pressures to be maintained for the entire tunnel length defined by stationing and soil/rock type, along with supporting calculations. Indicate tolerable limits for fluctuations in face pressure. • Calculated maximum grout pressures based on planned face pressures. • Longitudinal section of tunnel with minimum face pressures, target face pressures and maximum face pressures displayed every 10 rings in tabular format.

Work Plan Section	Initial Work Plan	Detailed Work Plan
	tunnel face for expected ground conditions described in the Geotechnical Baseline Report. This shall include cutterhead rotation speed and torque, thrust, screw conveyor rotation speed and torque, discharge rate, rate of advance, slurry/muck conditioning materials and mix quantities, and volumetric and pressure control of the screw conveyor and slurrifier box.	• Performance indicators for face support medium (slurry or bentonite or water suspension) such as density, viscosity for the entire tunnel length defined by stationing and soil/rock type. • Detailed plan for tunnel advance that address the following KPIs: i. Interpreted geology as a developed section including relevant boreholes and tunnel horizon; ii. Location plan indicating tunnel, structures and instrumentation; iii. important features and specific trigger levels; iv. Minimum, maximum and target face support pressure, and acceptable range of deviation; v. Position of water table or anticipated hydrostatic pressure; vi. Compressed air pressure (or free air pressure, if applicable) and/grouting required for intervention; vii. Minimum and maximum backfill grouting and corresponding tail seal grease pressure and volumes; viii. Rate/speed of advance of TBMs. ix. Anticipated thrust/torque values including maximum individual and overall thrust loads on each thrust cylinder; x. Location(s) of any ground treatment; xi. Postulated ground conditions; including type of conditioner and dosage rate; and xii. Planned cutterhead intervention locations.
4. Launch/ Holing through	Not required in initial work plan.	• Assembly of TBM. • Startup of TBM and the launch of TBM into ground through portal structure. • Details for TBM assembly with documentation of breakdown of weights of each major component with major dimensions, lifting points and center of gravity. • Lifting plan for TBM assembly and crane foundations which need designing

Work Plan Section	Initial Work Plan	Detailed Work Plan
		in conjunction with launch shaft/portal design. • TBM launching design and procedure. • Schedule for assembling TBM at Mackinaw Station Portal including startup time, and on-site training period. • Means for testing and verifying the effectiveness of ground treatment. • Details of the seals to be used at the structure walls and other measures to be taken to minimize loss of ground, maintain the minimum required face pressure, and to provide groundwater control while the TBM advances sufficiently to complete the installation of several liner rings. • Method of preparing for holing through into North Straits Shaft. Integrate with plan for prior performance of ground treatment, and removing bulkhead. • Details for tunnel and shaft structure interfaces. • Dismantling of the TBM and removal from site.
5. TBM Alignment Control	Not required in initial work plan.	• Detailed description of proposed TBM guidance system, how the control is brought underground, how it is used by the TBM operator to monitor TBM performance, how it interfaces with specified TBM operational systems, PCTL placement and grouting sequence to minimize deviations from the theoretical tunnel alignment, how it will be used to correct misalignment, and format of data to be provided to the Company. • Methods of correcting tunnel alignment if the specified driving tolerance is exceeded.
6. Grouting	Not required in initial work plan.	• Detailed description of the backfill, shield gap injection and check grout systems including mixes, methods, and procedures proposed, demonstrating that they provide the required strength, limiting deformation and set time characteristics. Include a description of the

Work Plan Section	Initial Work Plan	Detailed Work Plan
		grouting system to demonstrate the capability of complete, immediate, and uniform filling of the annular gap as the TBM advances, and how grout set time is designed to ensure consistency with the planned rates of advance of the TBM. Describe method of measuring grout/shield gap filling volumes and pressures and logic used to determine grout composition and pressures as a function of tunnel depth, rate of advance, ground, and groundwater conditions. • Product data and injection system for tail seal grease.
7. PCTL	Not required in initial work plan.	• PCTL ring erection procedure, considering clock position of the rings for straight and curved alignment sections. • Segment handling and transportation for each stage from the segment factory to delivery into the TBM until placement on the segment feeder. • Methods of measuring each PCTL ring, including checking the leading edge tolerances for planarity and for correcting PCTL ring non-planarity and/or non-circularity and corrective measures to be taken should specified tolerances be exceeded. • Details of the mechanisms by which the thrust cylinder shoes will be kept in their intended positions on the PCTL segments so as not to introduce any eccentric or excessive loads to the segments or gaskets creating a potential for damage, and intended corrective measures to be taken if thrust cylinder misalignment or liner or gasket damage should occur. • Method of repairing or replacing cracked segments including dismantling of rings. • Method to ensure segments are correctly positioned in rapid unloading system prior to lifting. • Method of installing and removing the key restraint system.

Work Plan Section	Initial Work Plan	Detailed Work Plan
8. General Maintenance	• Initial list and description of required TBM spare parts giving storage location and condition. • Planned Rescue and Emergency Drills.	Information in initial work plan, plus: • Overall operational procedures for the TBM including onsite assembly testing before startup, supervisory staff organization and site responsibilities for each position. • Planned TBM maintenance schedule • TBM inspection and maintenance program to keep all TBM equipment and systems in good operating condition. • Main bearing grease/oil sampling and lab testing program. • Final list of required TBM spare parts giving storage location and condition.
9. Cutterhead Maintenance	• Procedures to be used when stopping the TBM for interventions for access to TBM face for inspection, removal of obstructions, maintenance or repair in free air or using compressed air, methods to prevent TBM entrapment during stoppages, ventilation of working chamber, and other supplemental ground stabilization methods such as use of Clay Shock filler as required. Include description of measures to ensure attainment of target face pressure immediately at recommencement of excavation. • Methods for access to TBM face for inspection or removal of obstructions, including boulders, maintenance or repair using compressed air. • Procedures for sealing the face to limit air loss and procedures to restore safe and stable working conditions if air consumption increases steadily or rapidly. • Schedule identifying the number of planned interventions and their approximate locations along the alignment where access for inspection, repair or maintenance of the cutterhead is planned, and explanation based	Information in initial work plan, plus: • Details of the TBM air lock (applicable only if permanent airlock for bounce interventions is installed in addition to provisions for hyperbaric interventions) and compressed air chambers, including locking and bulkhead designs, the sealing arrangement, and the life support requirements. Include a detailed description of procedures for operating the air lock, effecting compression/decompression, operating details, communication protocols and an emergency work plan, including firefighting. • Complete hyperbaric work plan developed by a hyperbaric specialist consultant that includes method statements, equipment and procedures, personnel responsibilities and qualifications, training, medical clearance, medical supervision, decompression schedules, and all professional and support services for hyperbaric work. Include documentation as required by OSHA including for any variances necessary from OSHA to implement the Hyperbaric Work Plan. Compressed air equipment and procedures shall be in accordance with the approved hyperbaric work plan and OSHA requirements. • Details for transport, hospital treatment, and care of workers if needed.

Work Plan Section	Initial Work Plan	Detailed Work Plan
	on expected cutter wear and prevailing ground conditions.	
10. Tunneling Monitoring and Documentation System	Not required in initial work plan.	• Details of the Tunneling Monitoring and Documentation System, including the reported content, system schematics and the plan for how different database systems for TBM operational data, productions records, segment data and geotechnical data interact. • The list of items of data, both automatic and manual, that the TBM data acquisition systems will collect and report in real time.
11. Contingency Plans		Include contingency plans for potential scenarios with description of preventive and potential corrective measures, including as a minimum: <u>Difficult driving conditions</u> • Fault zone (e.g. loose section with high water pressure) in front of the tunnel face. • When excessive compressed air loss requires grouting ahead of TBM to stem high groundwater inflows. • Formation of soil/rock wedges at the tunnel face blocking the cutterhead. • Formation of soil/rock wedges resulting in overbreak along the shield. • Complete soft ground conditions. • Loss of suspension fluid with the temporary face still stable. • Cracking (drying out of bentonite seal coating) of the tunnel face during interventions. • Prevention of water migration along the tunnel and/or shield and into the temporary face during interventions. • Removal of all expected and/or unforeseen manmade obstacles within the excavation chamber. • Rotating of the cutterhead without advance as a result of clogged cutter(s) or blocked supply and feed lines (or screw conveyor). • Alignment recovery and steering of the TBM from outside of the allowed tolerance.

Work Plan Section	Initial Work Plan	Detailed Work Plan
		• Rolling of the TBM. • Subsidence of the ground below TBM invert exceeding the construction tolerances. • Exceeding the maximum contact force of the cutterhead. • Squeezing ground conditions encountered during normal TBM operation and/or stoppages requiring high thrust loads and potential injection filler in the radial gap between the TBM shield and the ground excavated surface. <u>Damage to different parts of the TBM</u> • Damage of cutterhead. • Failure of main bearing. • Failure of main bearing seal. • Description of methods for replacement of cutterhead main bearing and cutterhead seal(s) from within tunnel. • Leakage of the tail skin seals. • Exchange of tail skin seals. • Permanent blockage of annular gap grouting lines. • Fire on the TBM. • Flooding of the tunnel. • Deformation of the shield cutting edge. • Deformation of the tail skin. • Failure of the TBM segment erector and/or segment handling system. • Failure of the hydraulic systems. • Failure of the main power supply. • Failure of the programmable logic controller. • Failure of the guidance system. • Failure of the monitoring system for the injection pressure of the grout. • Failure of the data transfer system. • Power failure during chamber inspection. <u>Special conditions</u> • Spalling of the PCTL segments. • Steps and lips along the circumferential joint in conjunction with high deformation. • Water ingress in the tunnel. • High settlements at the ground surface or lakebed.

Work Plan Section	Initial Work Plan	Detailed Work Plan
		• Insufficient bedding of the PCTL segment. • Flotation of the PCTL rings in the backfill grout. • Shunt flow of grout/groundwater along tunnel and/or from tail end of shield to the cutterhead.
12. Geotechnical data collection		Groundwater Sampling: • Laboratory methods, detection limits, holding time, and sampling container requirements for identified analytes. • Sampling methodology. • Quality Assurance/Quality Control (QA/QC) methodology (including duplicate sampling and trip blank provision).

1.6 INFORMATIONAL SUBMITTALS

A. Qualification Data: Provide resumes or documentation of experience for the following individuals or companies identified in the Quality Assurance requirements to demonstrate the experience requirements are met:
1. TBM Manufacturer (if required).
2. Tunneling Project Manager.
3. Tunneling Superintendents.
4. TBM Operators.
5. Erector Operator.
6. STP Operator.
7. TBM Expert.
8. Slurry Designer/Consultant.
9. Hyperbaric Specialist Consultant.

B. The TBM manufacturer shall make a presentation to the Company on the design and layout of the proposed TBM prior to fabrication.

C. Certifications:
1. TBM manufacturer certification that the TBM as assembled is in compliance with the project requirements and is ready for operation.
2. TBM manufacturer certification that the operators and mechanics have completed the training and are qualified and ready for TBM operation.
3. TBM manufacturer certification of full and complete design coordination between TBM manufacturer, backup equipment manufacturer and PCTL manufacturer, including a list of all agreed design parameters.
4. Written declaration by TBM manufacturer confirming that they have reviewed the key components of the tunneling system and that the TBM and support systems will be

compatible and able to achieve the performance and schedule requirements of the tunneling works based on the anticipated ground conditions.

5. Contractor and PCTL manufacturer certification affirming the compatibility of TBM and backup equipment with PCTL, segment erector, and continuous backfill injection system.
6. Joint declaration by Contractor and TBM manufacturer confirming full functional testing and conformity with these specifications and associated codes and regulations.
7. Documentation and certification of main bearing and seal design conditions, calculations, and design life for the TBM to be furnished.
8. Include main bearing life cycle calculations against the following front face load cases:
    a. Full cutter load concentric to the TBM axis at maximum cutterhead rpm.
    b. 60% cutter load at 80% of time concentric and 20% of time at 1/3 TBM radius at maximum cutterhead rpm.
9. Calibration certificates for gas detection system, pressure cells in excavation chamber, TBM guidance system, thrust cylinders, and annular backfill grout volume and pressure gauges. Provide these certificates every 30 days during which TBM tunneling is taking place.
10. Certification on the sealing of the compressed air chambers (e.g. pressure vessel).

D. During fabrication of the TBM:
    1. A monthly report stating the progress of the design and fabrication with respect to the schedule and outlining any notable issues or occurrences.
    2. Monthly progress photographs demonstrating procurement of materials and fabrication.

E. Shipment packing lists in sufficient detail such as weight and dimensions of components to allow the Company to verify the arrival of all critical TBM components including spares. Provide this information a minimum one week prior to arrival of the TBMs in Michigan.

F. Prior to the delivery of TBM, supply of one electronic copy with a searchable index of the TBM operating manual, in English.

G. Field Reports:
    1. Provide access to the following records through the Tunnel Monitoring and Document System, including:
        a. Daily Reports as presented and discussed at the Task Force Meetings. Daily reports shall include labor, start and end station of the TBM, actual excavated material volumes per ring and comparison with theoretical volumes, PCTL ring data, deviations from work plan, or other unusual events.
        b. Weekly TBM performance metrics for the project, average daily advance, average TBM penetration or excavation rate, and utilization.
        c. Weekly report on the STP operation with complete analysis and summary of use of time, including all maintenance and delays. The report shall also include a summary of all equipment downtime with justification / reasons and a summary of dry weight of materials processed at each stage of separation for each shift.
        d. Air Quality Reports: Records of air and gas monitoring. Test and monitoring reports as required by regulations (for oxygen level and for dust, toxic and hazardous gases, and other atmospheric impurities in the working environment).
        e. Results of strengths and/or accepted tests for the backfill grout.
        f. All historic and real-time information recorded by the Tunnel Monitoring and Documentation system.
    2. Compressed Air – Records:

a. Provide records of all personnel working in compressed air, with the exception of personal medical records, every day.
b. Provide records for each person of the working pressure, compressed air working time, decompression time, temperature, humidity, and weather conditions daily during compressed air work.
c. Provide continuous records of air supply volumes and pressures in the working chamber and all locks throughout the total period of using compressed air in the work.
d. Provide records of compressed air quality monitoring.
e. Prepare, maintain, and provide records in accordance with OSHA and all applicable regulations and codes of Federal, State, and local agencies.
f. Provide records of compressed air consumption.
g. Details and records for onsite or of transport and hospital treatment of compressed air workers as required.

H. Test Reports: For the following, from a qualified testing agency:
1. Oedometer testing of Clay Shock clay-sand viscous filler mix at least 60 days prior to construction.
2. Slurry test data.
3. Water samples.

I. Tunnel Survey:
1. Final as-built survey of the tunnel within 90 days of completing excavation.
2. Interim updates to survey control every 500ft.

J. Notifications:
1. Notify the Company at least once month prior to TBM Factory Acceptance Test.

1.7 QUALITY ASSURANCE

A. Qualifications:
1. TBM Manufacturer: Herrenknecht, or alternative manufacturer approved by the Company who have supplied a similar TBM for at least three projects. A similar TBM is defined as a Slurry TBM that has excavated in closed mode under a hydrostatic pressure of at least 10 bar.
2. The Tunnel Construction Manager and Superintendents shall have completed at least one similar tunneling project using similar equipment. A similar project is defined as a similar diameter tunnel, longer than 2000 feet, in weak sedimentary rock and under a hydrostatic pressure of at least 5 bar.
3. TBM operators, master mechanics and electricians shall be certified as trained by the TBM manufacturer to work on and support the TBM before startup of TBM.
4. The TBM Field Services (Electrical) technical representative shall be knowledgeable in all electrical aspects, including PLC, of the TBM.
5. The TBM Field Services (Mechanical) technical representative knowledgeable in all mechanical and hydraulic aspects of the TBM.
6. Hyperbaric Specialist Consultant shall be knowledgeable in all aspects of hyperbaric work and shall have planned and completed hyperbaric interventions on at least one similar tunneling project using similar equipment.

B. Engage a recognized TBM expert (internally or independent) to visit the TBM manufacturing facilities regularly (on a monthly basis between months 5 to 8 during production/bi-weekly between month 8 until Factory Acceptance).

C. Allow the Company to visit the TBM workshop at any time during regular working hours, with a one week notice period.

1.8 PRECONSTRUCTION TESTING

A. Conduct TBM Factory Acceptance Test and demonstration tests inclusive of but not limited to shield dimensions, demonstrate cutterhead turning and reversal, extension / contraction of various cylinders, ground condition system, ring erector and handling mock segment, operation of the backfill grouting system under pressure at factory before shipping to worksite and onsite before launch of the TBM.

B. Carry out a minimum of three Oedometer tests of Clay Shock clay-sand viscous filler design mix in accordance with ASTM D2435 and the following additional requirements:
   1. Minimum backup reference effective stress pressure of 10 kPa (210 psf).
   2. Effective stress load increments (ΔP') between 1 and 2.5 hour intervals at constant strain rate.
   3. Maximum effective stress loading at 1000 kPa (21,000 psf).
   4. Carry out unload-reload loop after final effective stress load increment.
   5. Record test output and derivation of parameters in digital format.

C. Carry out a minimum of six Consolidated Isotropic Undrained (CIU) Triaxial tests of Clay Shock clay-sand viscous filler design mix in accordance with ASTM D4767 and the following additional requirements:
   1. Carry out at testing on different Clay Shock mix samples at three different effective confining pressures (p'); two tests at 500kPa (10,500 psf), two at 1000 kPa (21,000 psf) and two at 2000 kPa (42,000 psf).
   2. Measure and continuously monitor radial and axial strain of the tested sample.
   3. Apply deviatoric stress at a constant strain rate.
   4. Record test output and derivation of parameters in digital format.

1.9 DELIVERY, STORAGE, AND HANDLING

A. Not used.

1.10 FIELD CONDITIONS

A. Not used.

PART 2 - PRODUCTS

2.1 TUNNEL BORING MACHINE

A. The requirements in this Section are the minimum requirements for the TBM and associated tunneling equipment. Procure a TBM that is capable of excavating through the full range of ground conditions described in the GBR and the additional conditions defined in this section, and as determined by the Contractor to meet the schedule and performance requirements of the Agreements and Exhibits.

B. Design and supply a Slurry or VDM TBM, articulated as required, with the ability to operate in a pressurized mode. The TBM shall have the capability of:
   1. Excavating, maintaining face stability and withstanding all applied loads at all times under:
      a. All conditions as described in the GBR.
      b. In overburden deposits if unexpectedly encountered along the alignment, with:
         1) a TBM face pressure of at least 20 bar.
         2) a ground load on shield of 65psi in vertical direction and 75psi in horizontal direction.
         3) cobbles and boulders up to 60,000 psi in uniaxial compressive strength (UCS)
   2. Allowing hyperbaric interventions of up to a minimum of 17 bar.
   3. Allowing ground improvement ahead of the TBM.

C. The TBM(s) and all associated parts are to be new. Previously used and reconditioned components are not allowed.

D. Safety:
   1. Make adequate provision for the safety of the personnel and the application of safe methods of tunneling in the TBM design.
   2. TBM design shall comply with the most stringent of all applicable local, State, and Federal regulations.
   3. The TBM shall be equipped with mechanical and electrical systems required to ensure the safety of the tunneling operations including but not limited to communications, ventilation, lighting, pumping, and gas detection. Systems shall comply with all applicable regulations.
   4. The TBM shall be equipped with a continuous flammable and toxic gas monitoring system capable of monitoring methane, carbon monoxide, carbon dioxide, and oxygen and other gases required by regulations within the occupied working spaces, in accordance with OSHA 29 CFR 1926. The monitoring system shall signal the heading and shut down electrical power, except for emergency ventilation, emergency lighting and life safety support systems, when concentrations of hazardous or toxic substances exceed statutory limits.
   5. Make provision throughout the length of the TBM for the automatic detection of fires and manual activation for suppression of fires. This includes the provision of a fire curtain (with manual activation) sited at the trailing end of the TBM backup. Design the fire system for local humidity and temperature conditions in the tunnels and to handle the type of fire that may occur on the TBM.
   6. The TBM shall be provided with an automatic and manually actuated fixed fire suppression system at flammable fuel point sources, and with hand operated fire extinguishers.
   7. Ensure all hydraulic fluids in hydraulically actuated underground equipment and machinery are fire resistant.
   8. Include provisions for ensuring that personnel can gain safe access to any part of the TBM.

9. Provide a straight or direct escape route, as far as practicable, from the airlock to the tunnel walkway (applicable only if permanent airlock for bounce interventions is installed in addition to provisions for hyperbaric interventions).
10. The TBM shall have a refuge chamber which can accommodate a minimum of 20 persons including the TBM crew in case of fire. The refuge chamber shall be capable of being sealed against toxic fumes and smoke. The refuge chamber materials shall be 2 hour fire rated in accordance with EN 16191.
11. TBM electrical systems, ventilation and lighting and backup equipment shall conform to OSHA 29 CFR 1926.800. Essential services such as lighting, dewatering and ventilation shall be Class 1 Div 2 and stay energized.
12. The TBM shall be provided with a dewatering system with adequate capacity to keep the tail shield free of water and fines, for efficient liner installation. Provide sufficient pumping capacity in the tunnel during construction to remove accumulated water from construction discharges and groundwater seepage.

E. Spare Replacement Parts:
1. Maintain an inventory of replacement parts in accordance with the manufacturer's recommended spares list and the approved maintenance plan. Store spare replacement parts for the TBM at or near the project site.
2. Maintain one spare main bearing assembly and seals in a climate-controlled facility at all times over the duration of the TBM excavation. The spare shall be deliverable to the site within 2 weeks once TBM is ready for its replacement.
3. Provide spare parts that are considered critical and long-lead items for the TBM.
4. Maintain an inventory, recommended by the TBM and backup systems manufacturers, to ensure continued availability of the TBM and all essential systems.
5. Store on site replacement parts and maintenance materials which includes but is not limited to:
    a. One complete set of discs cutters, picks and scrapers.
    b. One spare main drive motor including any associated gear and clutch assembly stored off-site available from the TBM manufacturer for prompt replacement of the corresponding parts provided with TBM.
    c. Non-standard hydraulic rams, hydraulic hoses and components.
    d. One full set of tail seal brushes.
    e. One full set of fluid pressure sensors for TBM excavation chamber, working chamber and pipe lengths until pipe extension point.
    f. One spare main bearing seals to be kept in a controlled climate storage.
    g. Electrical and mechanical components including a full set of electrical components that are not readily available in Michigan.

F. Cutterhead and Wear Resistance:
1. The cutterhead shall incorporate a combination of disc cutter, picks (if required) and scrapers appropriate to excavate the ground condition described in the GBR.
2. Cutting tools (picks (if any), scrapers and disc cutters) shall be interchangeable from the rear of the cutterhead.
3. Provide a periphery cutter arrangement that allows adjustment of the cut diameter by shimming to achieve the required overcut to negotiate the specified tunnel curves and any correction curves for TBM steering. Provide at least two gauge cutters on the outer periphery track.
4. The cutterhead and spoil transport system shall reduce cobbles and boulders in size and accommodate their passage without special procedures.

5. Design the TBM for maximum abrasion resistance and durability based upon the anticipated ground conditions.
6. The TBM shall be provided with a remote reading wear indicator system for structural wear detection on the cutterhead.
7. Design the TBM cutterhead such that tunneling through soft eyes, ground treatment zones, etc. at launch and holing through is achievable.
8. Provide measures to prevent clogging of the TBM cutterhead, including at the center of the cutterhead.
9. The cutterhead shall be capable of clockwise and anticlockwise rotation and shall only be able to excavate the ground while the hydraulic rams are being actuated.
10. Provide a telescopic inspection camera that can be used to view the cutterhead and tools remotely under hyperbaric conditions.

G. Face Pressure Monitoring and Control:
1. Equip the TBM with pressure cells in the excavation chamber.
2. At a minimum, locate pressure cells at the invert, both sides on the springline and crown, along the screw conveyor (if applicable) and on the shield perimeter.
3. Provide a sufficient number of cells to ensure continued readings in the event of loss of an individual pressure cell.
4. Record all pressure cells data in the Tunneling Monitoring and Documentation System.

H. Cutterhead Drive System / Main Bearing System:
1. The cutterhead shall have sufficient drive motor power so the TBM is not torque limited while operating at maximum anticipated instantaneous penetration rate in any of the ground conditions described in the GBR and in glacial fluvial deposits incorporating cobbles and boulders if they are encountered along the alignment.
2. The drive system shall have the capacity to start the cutterhead with maximum torque and shall be capable of operating the cutterhead equally in either direction of rotation.
3. The design life of the main bearing shall be not less than 10,000 hours with a sealing system providing protection against contamination for the same period. Design the sealing system to accommodate the maximum anticipated face pressure with a minimum safety factor of 1.5.
4. The main bearing and sealing systems shall be tested and certified by the original manufacturer and verified for the minimum remaining design life of 10,000 hours.
5. Design the TBM to allow for replacement of the main bearing and seals from within the tunnel.
6. The bearing shall have facilities to allow access to the bearing raceways for vibration monitoring equipment and endoscope condition monitoring.

I. Shield Design:
1. The shield of the TBM shall be circular, strong enough to avoid distortion during driving and suitable for building the PTCL.
2. Optimize the TBM diameter to provide the required internal clearances while accounting for horizontal and vertical alignment requirements and to produce minimum over-excavation. The TBM and backup equipment shall be capable of negotiating the alignment within defined tolerances.
3. The TBM shall be capable to negotiate the minimum radius and gradient provided in the Agreement Drawings.
4. The TBM shield shall be articulated as required, to assist constructing the tunnel to the theoretical alignment indicated and within the specified tunnel construction tolerances.

5. Each articulation joint shall be provided with a seal, designed to withstand groundwater, grouting, and active face support operating pressures. Articulation joint seals shall be replaceable from within the TBM. Provide a means for maintaining the articulation joint from inside the TBM to ensure a full range of articulation.
6. Design the TBM body to withstand all loads and forces imposed by the ground and water and all loads and forces arising from operating the TBM including normal, degraded, accidental and emergency modes such as squeezing ground conditions. Give particular consideration to the loads and forces arising from operations to correct misalignment.
7. The design of the structures of the shield body shall be supported by Finite Element (FE) method calculations. Design the shield (including the tail skin) to withstand all loads and forces occurring from the ground and groundwater and all loads and forces arising from transport, erection, launch, dismantling, prolonged stoppage and operating the TBM, both in normal mode and in modes required to correct misalignment.
8. The TBM design shall consider sufficient tapering of shield for the length of shield and to be prepared for potential ground movements due to squeezing ground conditions to limit ground loading on the shield.

J. Thrust System and Steering:
1. Design the TBM to provide forward propulsion by thrust cylinders that react against the installed liner.
2. Operational thrust force shall not be less than 120 MN, and the total installed thrust force shall not be less than 155 MN, independent of whether the alignment is straight or curved. Provide this force from a series of hydraulic cylinders located around the shield circumference.
3. TBM thrust onto the segments shall be with thrust cylinder shoes sized to apply an average pressure no more than the design limits shown on the Agreement Drawings.
4. Provide additional steel shove plates to be installed when TBM is required to operate at very high thrust forces. Design the shove plates to be sufficiently rigid in order to apply an average pressure no more than the design limits shown on the Agreement Drawings and to have a minimum length of 3 feet (920 mm). These steel shove plates must be available on site for installation as required.
5. The capacity of the thrust system shall be sized to advance the TBM under the combined maximum loads of cutting tool, earth and hydrostatic pressure, shield friction, and trailing gear drag.
6. Ensure the thrust cylinder shoes are consistent with the liner type and joint design.
7. Thrust cylinders shall resist displacements when idle or shut down.
8. The maximum thrust pressure at any point and any time on the liner system shall be compatible with the liner design.
9. Assess TBM thrust force to consider requirements based on face pressure analyses during continuous excavation, stoppages and interventions accounting for the ground and water loading and frictional resistance of the interface between the shield and the ground.

K. Seals:
1. Main bearing seals shall be capable of accommodating anticipated conditions and maximum pressures resulting from applied forces inclusive of TBM operating characteristics.
2. Provide an automatic system of main bearing seal lubrication. If an oil based system is proposed, provide it with redundant filter systems for cleanliness to protect the main bearing, dirt detection, and alarm. The system shall be capable of monitoring oil pressures. Interior seals shall be capable of being changed from inside the TBM.

3. Design articulation joint seals, tail seals, and probe ports for maximum conditions of hydrostatic and earth pressure, plus pressures arising from injected shield gap slurry and annular backfill grout.
4. Tail seals shall comprise of a minimum of four seals, continuously fed with fibrous grease through pipes integral with the tail skin and evenly spaced around the circumference whenever the TBM advances to exclude the ingress of any grout being injected. In addition, incorporate a tail barrier (such as spring plates) on the outer surface at the rear of the tail skin to limit grout migration along the shield towards the face.
5. Tail seals, other than the rear seal, shall be replaceable from within the tunnel during tunnel operations. The tail seal and liner system design, fabrication, and installation shall be coordinated to ensure a competent seal is maintained along the entire alignment.
6. Tail seal grease shall be compatible with the liner system, shall be inert, and shall not contaminate the surrounding ground or groundwater. Tail seal grease shall not result in long term degradation of the liner concrete, the joint connector, the gaskets, seals or joint packers.
7. Tail seal grease shall have a proven track record in high hydrostatic pressure environments (> 7 bar) and be suitable for an anticipated working pressure of up to 17 bar. Suitability can be demonstrated through appropriate laboratory test data.
8. The TBM tail shall include a tail seal protector to protect the tail seal brushes from damage due to incorrect ring selection resulting in the PCTL touching the TBM tail shield.
9. Provide an emergency sealant material, such as CONDAT Emergency Seal or equivalent, available for use at any time.

L. Injection Systems:
1. Shield gap injection system for operating in slurry mode with the face pressure less than hydrostatic pressure:
    a. Equip the TBM with an injection system, capable of continuous injection of a gap filling medium, such as bentonite or similar material medium capable of supporting the surrounding ground under pressure through the shield. The medium shall fill and maintain the gap between the shield and the surrounding ground until such time as backfill grouting can be completed. Utilize injection ports in all shield sections and around the complete circumference.
    b. The injection system shall be capable of measuring and controlling injection pressures and volumes.
2. Clay Shock Injection System:
    a. Provide injection ports located in the TBM shield and tail skin to facilitate Clay Shock bi-liquid injection. The injection system shall comprise of at least 8 injection ports around the TBM shield and tail skin in such a way as to ensure that the material can be injected evenly into the void between the ground and the shield along the entire shield length.
    b. Equip the TBM shield with a system for injection of viscous Clay Shock filler through the shield injection ports. The injection system shall be such as to allow for simultaneous mixing in line with the supplier recommendations.
    c. The Clay Shock injection system shall be separate from the bentonite and backfill grout systems and include pressurized hoses allowing the bi-liquid to mix during the injection process.
3. Install sufficient pressure cells around the shield perimeter to allow pressure of injected medium to be measured.

M. Probing and Grouting Capability:
1. Provide the TBM with probe drilling and grouting capability, including:

a. Ability to probe ahead of the TBM and provide a minimum of 40ft of probe hole length ahead of the TBM at all times.
b. Ability to drill through the cutterhead and around the circumference of the TBM and grout. The location and number of ports shall be adequate to facilitate full coverage of the ground in front of the cutterhead and fully around the shield for ground stabilization in all ground conditions.

2. Provide drill hole penetrations with blow out prevention devices to prevent water intrusion into the tunnel.
3. Provide a suitable drilling method in potential unstable ground against high water pressures to be provided such as an ODEX system or similar.
4. High pressure grouting equipment for possible ground treatment, capable of a minimum capacity of 40 gpm at 50 bar pressure.
5. Provide sufficient grouting accessories including high pressure hoses, bypass valves, single and double packers, drill rods, drill bits, etc. to facilitate efficient pre-grouting ahead of the excavation face.
6. Provide a data logger to measure the main drilling and grouting parameters with reasonable frequency and be connected to the Tunneling Monitoring and Documentation System.

N. Crusher and Screw Conveyor (if used):
1. Design crusher and screw diameter to handle any blocks or boulders that could enter through the cutterhead openings.
2. If a slurry TBM is selected, design the crusher designed to be as accessible as possible from the working chamber to simplify maintenance during pressurized interventions. Consideration for different crusher types shall be given and justification for type and size of crusher presented at early TBM design development stage
3. If a VDM is selected, equip the crusher above the slurrifier box with replaceable tools, not indented rollers. Crusher drums shall be as large and powerful as possible. A deep access hatch after the screw discharge gate shall be available to allow replacement at atmospheric pressure of all crusher picks, lining wear plates and to remove boulders.

O. Spoil Handling and Treatment:
1. Provide TBM controls capable of preventing any over-pressurization of slurry in the excavation chamber.
2. Include provisions to prevent clogging throughout the spoil handling system and to break up balls of clay or other lumps of material before they enter the discharge pipes.
3. Keep a minimum of two spare booster pumps together with all associated valves and controls at site.
4. The slurry transportation system shall be capable of continuously measuring density and flow of the excavated material volume while cutting. Provide a minimum of two independent methods to give redundancy and backup in the event of mechanical problems with one system. The system accuracy shall be within 1.0 percent of the measured unit. The spoil measurement systems shall be linked to the Tunneling Monitoring and Documentation system to report excavated volumes on a real time basis and to provide comparison with theoretical values.
5. Slurry and other water discharged from the works shall be passed through water treatment facilities before being discharged in accordance with Section 312320 “Water Treatment and Disposal”.
6. Conditioners shall conform to all applicable regulations and shall be biodegradable.

P. Segment Erector:
1. Design the erector to grip and erect the segments such that:

a. Segments are positioned accurately.
b. Segments are installed in true shape and segment faces are planar.
c. Segments are aligned within the required tolerances.
d. Gaskets are fully compressed.
e. Segments and/or gaskets do not experience damage or distortion.

2. Equip the TBM with a computerized ring selection system for determining ring type and orientation that is linked to the TBM guidance system to optimize segment/curve alignment.
3. The TBM shall also be equipped with a positioning device to indicate the correct radial and circumferential location of the segments within the tail shield. The positioning device shall continuously measure the gap between the liner and tail shield to supply data for the ring orientation computer program, which shall be linked to the TBM guidance and the Tunneling Monitoring and Documentation System.
4. Design the segment erector to compress the gaskets against adjacent segments prior to tightening of the bolts.
5. The erector shall be capable of disassembling the last fully erected ring within the first 1.5 feet of the next TBM advance to allow for repair and replacement of wire brush seals or to retrieve damaged or misaligned segments. This also requires the erector to be able to overcome the pullout strength of the circumferential joint connectors (dowels) or for them to be cut through.
6. Lift and erect the segments using a vacuum lifting equipment within the TBM. The segment erector shall be capable to maintain or hold the segment in the event of power failure as stipulated in EN16191.
7. Provide a means of safe access for the operatives to reach the segment fixing positions. During segment assembly, ladders and platforms shall be provided to enable personnel to reach all PCTL segment bolt connection holes. Where possible all working platforms shall be fitted with safety handrails and toe boards. Platforms shall be fitted with appropriate safety systems to prevent collision with the erector.
8. Fit the segment erector and segment feeder with audible and visual alarms that activate prior to movement.

Q. Annular Backfill Grouting System:
1. The TBM shall provide continuous and complete backfill grouting of the annular gap between the PCTL and overcut surface in accordance with Section 317117 “Backfill Grouting” with a two-component grout system.
2. Provide a computer operated grouting system, integrated with the real time Tunneling Monitoring and Documentation System, which considers the excavated volume, rate of advance, grout quantities, prevailing pressures and other related variables to continuously adjust required volume of grout and pressure.
3. The backfill grouting system shall be comprised of pipes or channels designed by the TBM manufacturer and embedded within the tail shield. The grout pipes shall be uniformly spaced around the tail shield with a redundant pipe at each location in the event that the primary pipe becomes blocked and shall be sufficient in number to provide for adequate supply of grout to fill all surrounding voids.
4. Provide means of clearing blocked grout pipes.
5. Primary grouting of the rings as they leave the tail skin shall be continuous as the TBM advances, with no lag between annulus gap volume being created by the TBM advance and being filled with backfill grout.
6. Grouting through liner grout holes will not be accepted as the primary method of annular backfill grouting.

7. Provide the TBM with a lock out system to prohibit TBM advance unless backfill grouting systems are fully operational.
8. Grout pressure and flow shall be maintained at all times while the shield is advancing with varying speeds.
9. Provide a method of automatic data logging measuring the volume and pressure of grout injected at ten second intervals during advance. Corresponding records shall be linked to each PCTL ring.

R. Guidance System:
1. The TBM shall be provided and operated with a guidance system capable of supporting the TBM operator in accurately steering, tracking and continuously recording TBM location and permitting continuous control and setting of alignment and grade.
2. Provide the TBM with a lock out system to prohibit TBM advance unless the guidance system is fully operational.
3. The guidance system shall facilitate construction of the PCTL so that it follows, and does not bind into, the TBM tail skin. The system shall provide data defining the plane of the circumferential joint on the leading edge of the PCTL ring with respect to the designed tunnel alignment and actual TBM axis.
4. The guidance system shall include an automated measurement system, which consists of a minimum of five distance measurement lasers.
5. Equip the tail skin of the TBM with a minimum of eight high precision distance measurement sensors to automatically evaluate the clearance between the extrados of the tunnel segment and the tail skin. The values shall be integrated in real time into the ring sequencing calculation software to determine the subsequent ring with regards to the current TBM position.
6. Ring Convergence Measurement:
    a. Monitor ring deformation and convergence in at least four positions.
    b. The measurement must start after the ring has been built and before the TBM advances.
    c. Record the convergence measurements with high frequency (ten minute) for at least the first ten advances after ring build.
    d. Provide a wireless measurement system to avoid interferences during the tunnel activities.
    e. The software shall be able to combine the convergences with 3D measurements to obtain absolute ring movements (rising or sinking).
    f. The software must graphically and numerically provide an output of the changes calculated compared to the selected reference measurement. All data must be accessible in real time.
    g. The accuracy of the system in a static condition shall be ± 1/16 inch.

S. Supply and maintain a Tunneling Monitoring and Documentation System throughout the project duration, consisting of:
1. Software including, but not limited to, database software, database management system, front-ends, interfaces and backup utilities.
2. Software to be:
    a. Tunneling Process Control (TPC) by BabEng/tunnelsoft, or
    b. Procon by Maidl Tunnelconsultants, or
    c. IRIS by ITC, or
    d. Similar approved by the Company.
3. The software shall provide as a minimum the following general features:

a. Web based, with internet based data transmission, accessible anywhere from any browser or machine including smartphones and tablets, with secure authorization and security.
b. Data Storage: Able to receive and store all project data in a central database.
c. Data Visualization: The software shall permit real-time display, in numerical form, of all data, such as trend indicators, status indicators and graphs or logic elements which are based on time, ring number and tunnel station.
d. Mathematical Module: The software shall offer a mathematical module to permit the individual creation of additional information/indicators, based on existing data. The additional information/indicators, together with all other data, shall be calculated and displayed in real time on the main software and all subsystems.
e. Reporting: The software shall permit the individual user to design reports within the software and/or provide technical support to develop report templates based on users requests. The user shall be able to organize individually, the timing and distribution of reports, as well as the visibility of reports according to the individual user's role.
f. Monitoring and Notification: The software shall monitor the actual tunneling process. It shall alert and notify if any parameters indicate deviation from the expected data range. The monitoring and notification system shall be fully customizable. It shall permit to select the data to be monitored on 24/7 basis and shall allow for individual trigger settings, depending on the TBM operation mode, the chainage and the time. The notifications shall be distributed according to user roles and the stage of escalation, and shall be sent by email, SMS, application push notifications and on special software screens.
g. Mobile Subsystem: The software shall offer mobile solutions as applications for mobile devices, to display and manage real-time data (continuous live stream or single screen shots), historical data (including trend charts), notifications, shift reports (display, manipulation and sending), instrumentation data (including trend charts) and QA/QC for PCTL including repair documentation.
h. The Company shall have full access to the software with all functions.

4. Provide immediate and permanent data transmission of the raw sensor readings without delay or interruption and with associated time stamp and source information. Transmission shall occur as soon as the data is generated by the installations.
5. Data retrieval frequency of a full set of data shall be not larger than two seconds, not limited by the number of indicators.
6. Uninterrupted remote internet access to the software. Connection shall permit for unlimited maximum licensed users, parallel and simultaneously. Access shall be secured and encrypted.
7. This data shall incorporate relative to advance and time, all respective concentrations, relations, weights, volumes, pressures, temperatures, rotation speeds, strokes, elongations and indications for all functions and machineries. At a minimum, the data from the following tunneling systems shall be measured, digitalized and integrated into the software:
   a. Excavation equipment machines and interrelated parts.
   b. Material handling systems from the working chamber to ground surface, including separation plant.
   c. Sealing systems.
   d. TBM and backup.
   e. Thrust and steering systems.
   f. TBM and tunnel guidance data.
   g. PCTL installation, including type and position, clearance inside shield tail before and after installation.
   h. Backfill grouting of PCTL.

i. All consumable materials.
j. Safety including breathable air components.
k. Ground probing and prediction systems.
l. Ground water management and discharge.
m. Compressed air equipment.
n. Cutterhead structure wear indicators.

8. None of the data, whether generated manually or automatically by the TBM installation and equipment, shall be withheld from the software.
9. Shift Reports: Integrate shift reporting into the software. Automatic readings shall be available in real time. Manual readings shall be integrated into the database not later than 2 hours after end of shift. Shift report data shall be available for each shift worked, including periods when the TBM is not excavating, and include:
    a. Labor assigned to tunneling work, including surface support and STP operation.
    b. Start and end station of the TBM.
    c. Actual excavated material volumes per ring using slurry discharge rates and densities and comparison with theoretical volumes.
    d. PCTL ring data.
    e. Description of delays of individual or cumulative duration greater than 15 minutes.
    f. Deviations from work plan, or other unusual events.
    g. Cutter and muck system component changes, including time and date of replacement, cutter or component position or number, and reason for change(s).
10. Ring Reports: For each erected ring, complete an individual record survey of all relevant construction information, including:
    a. Charts of the most relevant TBM operational parameters throughout the shove, including:
        1) Face pressure.
        2) Cutterhead torque.
        3) Thrust force in each thrust cylinder.
        4) Instantaneous advance rate.
        5) Excavated soil weight.
        6) Tail void grouting volume.
    b. Segment ID numbers.
    c. Time shove started and finished.
    d. Time PCTL ring erection started and finished.
    e. Orientation of PCTL ring (position of key).
    f. Roll of ring.
    g. Type of face support medium used.
    h. Volume of bentonite or Clay Shock injected into the shield gap.
    i. Grout pressures and quantities for each injection port, and comparison with theoretical tail void quantity.
    j. Delays during shoving or PCTL erection.
    k. Any damage to PCTL segments or gaskets during erection or after start of shoving for the next ring; correction of such damage or replacement of damaged liner or gasket; changes to means or methods to prevent recurrence.
    l. Measurements of horizontal and vertical diameters from specified ring convergence measurement system for each ring.
    m. Problems encountered such as water seeps.
    n. Material classification records from STP.
11. User Generated Reports: Provide functionality to allow users to generate their own reports, including:
    a. Time and tunnel station at start of shove.

b. Guidance system information.
c. Predicted and actual face pressures, pressure distribution, and median pressure per shove.
d. Working chamber pressures during shut down periods.
e. Cycle times for excavation and installation of a ring.
f. Penetration rate.
g. Total thrust.
h. Ram pressure.
i. Cutterhead direction.
j. Speed (rpm) and torque.
k. Predicted and actual spoil volume.
l. Presence of boulders and other obstructions.
m. Predicted and actual shield gap injection volume and pressure distribution.
n. Predicted and actual backfill grouting volume and pressure distribution.
o. Tail seal grease volume.
p. Main bearing grease and oil lubrication pressure flow and temperature.
q. Electrical load characteristic.
r. Slurry pressure and flow rates for slurry mode.
s. Excavated material apparent density.
t. TBM backup towing loads.

12. Tunnel Air Quality:
    a. Air quality monitoring data shall be collected in the software in real time and monitored.
    b. Implement trigger levels for all individual sensor types to give a) alert, and b) warning by immediate notification if pollution exceeds allowable levels are reached.
    c. The software shall send out the alarms as well as pass the information directly to the TBM operator.
    d. Air quality data, as well as the receipts of confirmation of alarms, shall be recorded and stored.
13. Data Integrity:
    a. Ensure data integrity in every project phase.
    b. The system shall be fully redundant with a recovery time objective (RTO) of 2 hours and a recovery point objective (RPO) of 24 hours.
14. On completion of the project, provide a copy of all information in the database in a format acceptable to the Company.
15. All functions, or specific elements, of the Tunneling Monitoring and Documentation System can be combined with the Segment Tracking Database specified in Section 317416 “Precast Concrete Tunnel Lining”. Alternatively, the Tunneling Monitoring and Documentation System can be accomplished by using two or more separate databases (e.g. one for shift reporting and one for TBM data records) as long as the information can be linked by the tunnel station and unique segment ID numbers.

T. Cutterhead Interventions:
1. The air locks shall be designed for safe operation under the maximum hydrostatic pressure to which the TBM is anticipated to be exposed, with an appropriate factor of safety. The air locks and support equipment shall be designed for frequent use. Feed-throughs, independent of air lock(s), shall be provided for electrical power, water supply, fire suppression system, high and low pressure air, welding and any other service lines required. An efficient means of purging all hazardous gases prior to worker entry shall be provided.

2. Provide a safe method of draining water from cutterhead during a free air, compressed air or hyperbaric intervention.
3. Provide for safe methods of working for personnel carrying out work in the excavation chamber on the cutterhead including mechanical aids for the transport of tools and equipment into the cutterhead.
4. Provide access for safe transport of the hyperbaric shuttle from the surface to the air lock. Determine allowable duration for shuttle journey and provide for access within this time limit.

U. Virtual Reality Training Equipment:
1. Provide 3D BIM Model, VR models of the TBM, necessary hardware and a minimum of five pairs of Hololenses (or equivalent) to allow VR training for, at a minimum, segment erection and emergency and rescue drills.

2.2 COMPRESSED AIR EQUIPMENT

A. Provide, install and maintain at the working site compressed air equipment complete, as specified below, including all the necessary compressors, motors, air receivers, after coolers, all piping to air locks, valves, firefighting facilities, switchgear, electric cabling and all electrical apparatus complete, concrete foundations and plant houses prior to the launch of the TBM.

B. The main air equipment shall be capable of delivering air to the working chamber at the maximum pressure envisaged to be required during tunneling. The equipment shall consist of not less than three units having approximately equal capacities. An alternative supply must be available for all airlocks.

C. The hyperbaric medical chambers shall be provided by an approved specialist contractor.

D. Calculate the required volume capacity of the equipment to suit the expected ground conditions, maximum face pressure and airtightness. Provide plant to supply the required volume with adequate reserve capacity for emergency situations, and a minimum of 2,500 cfm.

E. Ensure all compressors are oil free. They shall be electrically driven, and shall all have diesel motors as standby which will cut in automatically in case of electrical failure; alternatively, standby diesel generators with cut-in features would be acceptable.

F. Controls shall be such that the pressure can be adjusted to suit face conditions and will remain at all times within 1 psi of the intended pressure.

G. The utmost care shall be taken in the design and construction of the compressor house to keep the noise level to the practicable minimum. A satisfactory soundproof insulation shall be provided in the roof and side of the compressor houses, which shall also house the high pressure compressors.

2.3 AIRLOCK

A. If a permanent airlock for bounce interventions is provided in addition to provisions for hyperbaric interventions the TBM shall incorporate a two-compartment airlock, with the main compartment designed adequately to accommodate three people, for access to the cutterhead and face in line with OSHA regulations.

B. The inner lock shall be able to accommodate a six foot long stretcher and two attendants for emergency rescue operations. Doors shall be capable of being opened without manipulation of the stretcher and patient. The airlock compartments and the airlock doors shall be strictly designed and sized to comply with Federal and State OSHA and ASME PVHO regulations and shall ensure safe and easy access of tunnel personnel to the excavation chamber. The airlocks and all paraphernalia required for safe operation shall be factory fitted and comply with Federal and State OSHA and ASME PVHO regulations.

C. The TBM shall be designed for safe entry and working in the excavation chamber. There shall be provisions against ingress of material and water during cutterhead inspection and maintenance such as compressed air face support in combination with suitable filtercake/membrane to seal the face to minimize risk of air losses. The man lock can be used as material lock and shall be designed for transportation of all maintenance tools and cutters, etc. into the excavation and working chamber. The lock shall be dimensioned such that it provides adequate facility to pass items such as roller disc cutters, tools, rotary coupling elements, etc. into the excavation chamber under compressed air.

D. The door for working chamber entry shall open into the airlock.

E. The TBM shall be supplied with built-in humidity, temperature and oxygen monitoring devices in entry lock and airlock. Built-in air, carbon and oil pre-filters shall also be provided outside the airlock and before the mass control valve to cleanse and purify compressed air and to supply good breathing air to cutterhead and airlock on top of pre-filter system installed on surface.

F. The TBM shall be supplied with a factory-fitted chiller unit connected to the Compressed Air line to regulate wet-bulb temperatures inside the working and evacuation chamber to comply with prevailing regulations.

G. The piping layout at the TBM man lock control panel shall have check valves on all air lines going to the TBM air lock control panel. There shall also be duplicate pressure controllers to the TBM air lock control panel. There shall also be check valves or flow restrictors installed on the connections to the air locks.

H. In addition to hyperbaric extinguishers, provide the air locks with fixed internal firefighting systems.

I. The TBM air lock system shall comply with OSHA and ASME PVHO requirements. Aspects which are not covered within these regulations such as saturation diving shall be developed and proposed by specialist contractor and their hyperbaric consultant in line with the planned intervention process requirements. Consider the following items in the development of air lock system design:
   1. Check valves on the pressurization / compression airlines to the main locks. Check valves installed after the pressure controller.
   2. Flowmeters.
   3. Alarms at the control panel.
   4. A backup air system with clear operation procedures.
   5. The barograph recorders shall be 1 revolution / 4 hours with the zero pressure on the chart periphery.
   6. O_2/CO_2 analyzers and a calibrated temperature and humidity gauge.
   7. Sound powered phones.

8. Mesh guards / strainers installed on all exhaust / exit piping inside the air locks to prevent accidental ingress of foreign material.
9. Under no circumstance shall hoses be draped through doorways preventing the doors from closing.
10. Communication system installed at the air lock control panel.
11. In addition to video cameras, the air locks shall have adequately sized view ports for the air lock attendant to view personnel inside the air locks.

2.4 SLURRY TREATMENT PLANT (STP)

A. The STP shall be designed by specialists with experience in the operation of this type of equipment.

B. The STP shall be capable of being expanded to increase operational capacity should the need arise. Such expansion or any additions or modifications to the STP shall be approved by the STP supplier.

C. Monitor the slurry feed and discharge density as near to the TBM cutterhead as possible, along the slurry transportation lines and at all appropriate separation stages of the STP.

D. The STP shall include levelling device to automatically track the levels of the slurry in the active tank, and information shall be fed back to the excavation management system.

E. The dry mass of all excavated and discharged material in slurry TBM and the STP shall be measured for checking against the theoretical excavated mass, at the STP, for purpose of verifying the mass of excavated earth derived from readings recorded by density and flow meters.

F. Provide a full acoustic enclosure over and around the STP and muck-pit areas to contain the noise and prevent disturbance.

G. All STP main components shall be monitored real time with visualization and data acquisition provided in the STP control room and linked into the Tunneling Monitoring and Documentation System. The minimum components to be monitored are primary and secondary screens (weight/hour); fresh bentonite added to active system, waste slurry removed from active system, active tank levels, fresh and waste tank levels volume; solid material separated (weight/hour).

H. The STP and TBM monitoring systems shall be compatible to allow the overall control of slurry volume in the active circuit for each TBM.

I. Provide sufficient holding tank capacity to meet the requirements for slurry treatment for the TBM. This capacity includes sufficient capacity for slurry/water being treated before discharge as well as sufficient capacity for holding of fresh hydrated bentonite to allow full replacement of active slurry for the TBM circuit.

J. The STP shall be suitably designed and operated in a manner to ensure that a slurry density appropriate to the prevailing ground conditions is continuously supplied to the TBM.

K. The STP shall be suitably designed with testing points so that routine testing at various stages of separation can be safely and easily carried out with minimum time.

L. The STP must be capable of being operated and maintained in all weather conditions.

2.5 GROUT

A. As specified in Section 317117 “Backfill Grouting”.

2.6 VISCOUS CLAY SHOCK FILLER

A. Provide Clay Shock product supplied by TAC® Corporation, or similar product approved by Company.

B. The Clay Shock filler mix composition shall conform to all the supplier’s testing and material requirements.

C. The Clay Shock filler design mix composition shall be such as to achieve the following key performance requirements:
   1. Design mix with a minimum viscosity of 1.3-lbs-s/ft^2 (650-dPa-s)
   2. Design mix with a maximum shear strength of 15psf (0.71kPa) at zero confining pressure tested using a shear vane.

D. The Clay Shock filler reference mix composition is provided based on available information from TAC® Corporation:
   1. Liquid A: 26-lbs/ft^3 (420-kg/m^3) clay-sand TAC-Beta2 material, 6.3-gal/ft^3 (839-L/m^3) water.
   2. Liquid B: 0.37-gal/ft^3 (50-L/m^3) Waterglass TAC-3G material.

E. The Clay Shock design mix composition shall be based on the reference mix composition, adjusted as needed in order to achieve the performance requirements, and demonstrated with the specified preconstruction laboratory testing.

2.7 PRECAST CONCRETE TUNNEL LINING SEGMENTS

A. As specified in Section 317416 “Precast Concrete Tunnel Lining”.

2.8 KEY RESTRAINT SYSTEM

A. Engage a Registered Professional Engineer licensed in the State of Michigan to complete the design of the key restraint system in accordance with the requirements shown on the Agreement Drawings.

B. Select material(s) for fabrication and incorporate handles for lifting to suit handling, installation and removal methods.

C. Fabricate, at a minimum, one spare key restraint system.

2.9 TUNNEL VEHICLES

A. Vehicles within the tunnel may include, but are not limited to, multipurpose service vehicles (MSV).

B. Fit vehicles used within the tunnel with a physical or electrical speed limiting device capable of restricting the top speed available to the operator to a predetermined maximum. Propose this maximum top speed for acceptance by the Company; the maximum top speed may need to be adjusted during the duration of the project to suit prevailing conditions.

C. Only appropriately trained operatives shall be permitted to operate MSVs, other haulage plant, gantry cranes or any other lifting equipment. Each such operator shall be adequately trained by the equipment supplier in the correct and safe use and shall hold a certificate stating that they have been so trained.

D. Provide a fully electronic tagging (RFID barcode or similar approved) site entry system for workers and all equipment/vehicles.

2.10 SOURCE QUALITY CONTROL

A. At a minimum, include the following items in the Inspection and Test Plan:
   1. Surveillance:
      a. TBM manufacturing (by TBM expert).
   2. Review:
      a. Not used.
   3. Verification:
      a. All specified certifications.
   4. Witness Point:
      a. Not used.
   5. Hold Point:
      a. Factory Acceptance Test.

B. Prior to the delivery of the TBM to site, obtain factory acceptance for all functions of the TBM with a performance test. The Factory Acceptance Test shall be jointly carried out with the Company, Contractor, the Designer and TBM expert engaged by the Contractor. The TBM shall be completely assembled in the TBM manufacturer's workshop with all necessary equipment installed to fully demonstrate its working order.

C. Sample segments shall be available to demonstrate the segment handling procedure.

D. Prior to disassembly of the TBM in the factory, issue a joint declaration with the TBM manufacturer of full functional testing and conformity with these specifications and associated codes and regulations.

PART 3 - EXECUTION

3.1 TBM TRANSPORT

A. Prior to TBM delivery, conduct a detailed study of traffic and road bearing capacity of the TBM transport route and a vehicle assessment for the TBM transport and clearance to avoid damage to the road assets and road congestion. Prepare a detailed Transport Route Study.

3.2 TBM ASSEMBLY

A. When delivered to site assemble the TBM in the portal to the required grade and line.

B. Provide adequate provision for TBM component storage and safe TBM erection.

C. After reassembly at site, retest the TBM and recalibrate all components.

D. Assemble tail shield to a maximum tolerance of ±0.25 inches in external diameter and ±0.75 inches in external circumference, or as specified by the manufacturer.

E. Before TBM launching and startup operations, the following preparation and installations are required:
   1. Before commencement of tunnel launch, ensure that all specified geotechnical instrumentation has been installed, is functional, has been baselined and is being monitored as specified in Section 310913 “Geotechnical Instrumentation and Monitoring”.
   2. The guidance system is fully functional and delivers accurate absolute and relative TBM position to DTA.
   3. The guidance system output position equates to the TBM commissioning survey position (obtained from a survey of the outside of the TBM in the shaft) and equates to the TBM position from a manual survey of internal survey targets.

3.3 TUNNEL BORING MACHINE OPERATION AND MAINTENANCE

A. Operate and maintain the TBM in accordance with the manufacturer’s guidelines and recommendations.

B. Ensure that all TBM operations are under control of the TBM Tunnel Superintendent at all times.

C. Training:
   1. Utilize a Virtual Reality Training Center, or similar approved method, to train Tunnel Construction Manager, Superintendents, TBM operators and other tunnel labor as required, for TBM activities such as segment erection and emergency and rescue drills.
   2. Training by the TBM manufacturer shall continue after launch and during excavation for a minimum of 3 months or 1500 feet of tunneling, whichever is greater. Include training in face pressure control, thrust cylinder control, performance monitoring and corrective measures.
   3. The STP operators and maintainers shall be trained by the STP manufacturer prior to the start of tunneling. A technical representative from the STP manufacturer knowledgeable in

the assembly, operation, maintenance and repair of the STP shall be present at the construction site for the whole duration of the tunneling works.

D. A minimum of two technical TBM Field Services representatives (one Electrical, one Mechanical) from the manufacturer knowledgeable in the assembly, operation, maintenance, and repair of the TBM, shall be on site throughout the entire duration of TBM operations of the project from TBM assembly until TBM disassembly.

E. Prior to launch of the TBM, and before tunneling is resumed after an intervention or unplanned stoppage station, ensure appropriate measures are in place that allow for attainment of target face pressure immediately at start or recommencement of excavation.

F. Provide suitable means to prevent ground loss during launch or hole-through of TBM. During removal of the TBM, ensure that all rings in the vicinity of the shaft are fully braced, grouted, and secured.

G. To prevent damage to the cutting head, as a minimum, perform an initial inspection and replacement of worn cutting tools as necessary on the TBM within 600 feet of commencing the drive. Adjust the frequency of inspection thereafter based on actual wear experienced.

H. Tunneling work shall be continuous in mandatory zones with high density slurry support (in areas of low rock cover and close proximity to lakebed) without stoppages and with interventions limited to the minimum extent possible.

I. Do not advance TBM without both the computerized guidance system and data acquisition systems in operation and functioning correctly. Conduct checks periodically on the TBM guidance system to verify its ability to supply accurate information to the TBM operator.

J. Maintain the fire system in an efficient operating condition at all times with a minimum water pressure of 1.5 bar.

K. Perform tunneling works within the following alignment tolerances:
   1. Tolerance from centerline alignment shall be 3-inch vertical and 3-inch horizontal (6-inch circular target).
   2. Recovery from alignment deviations shall not exceed 0.5 inch per 5 feet.

L. During periods of extended stoppage, maintain positive support of the tunnel face and a full working chamber and relevant personnel on duty 24/7 to regulate face pressure as needed.

M. During periods of extended stoppage or when utilizing more 110 MN total TBM thrust to advance, or when it is believed tunneling is occurring in squeezing ground conditions:
   1. Prevent TBM entrapment by positive means such as injection of Clay Shock viscous filler filling the entire radial gap around the TBM shield using pressurized injection ports in the shield and/or tail skin.
   2. Only use procedures that have been reviewed and accepted in the approved work plan and Clay Shock supplier method statements.
   3. Make every effort to avoid stoppage of the TBM. If a stoppage is unavoidable, limit to as short a duration as possible and ensure radial gap is filled with Clay Shock filler injection.
   4. Verify that the Clay Shock filler has filled the entirety of the gap between the shield and the ground prior to reduction of face pressure and carrying out interventions in Pointe Aux Chenes formation.

5. As required, perform ground treatment ahead of the TBM face in addition to Clay Shock injection to limit groundwater inflows and stabilize the ground, reducing the effect of squeezing ground.

N. Utilize additional steel shove plates when TBM is required to operate at a thrust that imposes pressures on the bearing area of the PCTL in excess of the limits on the Agreement Drawings.

O. Hold Daily Task Force Meetings for each day of active excavation. Present and discuss the daily reports for each shift, including periods when the TBM is not excavating.

P. Pump the grout backfill continuously as the TBM advances to ensure complete filling of the annular gap.

Q. Implement a main bearing grease/oil sampling and laboratory test program.

3.4 SLURRY MODE OPERATION

A. Operate the TBM in full face pressurized mode. Provide full excavation face support with a homogenous excavated slurry mix appropriately modified with bentonite (if required) to allow for maintaining of face pressures and creating filtercake/membrane in soils and in rock with high permeability within plus or minus 0.3 bar of the target calculated face pressure.

B. Design the TBM, STP and slurry transportation system, to also allow the TBM to operate with a slurry mix with a “water-rock fine suspension” if excavated material conditions allow.

C. Identify the required slurry characteristics including rheological parameters, filtration properties, density and characteristics such as recycling, performance in contaminated ground and disposal.

D. All additives including coagulants, flocculants, and polymer encapsulators shall be selected after trials on the ground at the tunnel horizon. Appropriate dosages shall be determined and fine-tuned during the operation of the STP.

E. Demonstrate how the bentonite and any other additives used comply with the applicable local environmental regulations.

F. Review rock test data for each ground type to be encountered, including slake durability and plastic viscosity, to understand the interaction between the ground and the mechanics of the TBM cutting action and slurry transportation process and the effects of breaking down the materials due to mechanical action and liquefaction. Estimate grain size distributions, accounting for the breakdown of the ground due to mechanical action and liquefaction.

G. Conduct tests on the density, gradation of the slurry and bleed under pressure. The effects of ground and groundwater chemistry shall also be taken into account.

H. Test the sand content of the slurry at all appropriate locations which shall include both at the main slurry discharge to the STP and after the secondary processing stage to monitor and control the fines separation stage.

I. Daily perform marsh funnel flow tests at the point of main slurry feed to the TBM to ensure the slurry is of suitable viscosity.

J. When tunneling in ground with high permeability, perform filter loss tests at the point of main slurry feed to the TBM to ensure the slurry is capable of sustaining a filter cake at the tunnel face.

K. Routinely perform gel strength tests using a Fann viscometer to test for the presence of reactive clays and for confirming the properties of the slurry used to fill the face during stoppages and prior to cutterhead interventions.

L. The TBM Operation Parameters Sheet and in particular the TBM advance and slurry flow rate shall be prescribed based on the overall processing capability of the STP and shall take into account the slurry requirements of the TBM. Any constraints on the TBM performance based on the design of the STP must be clearly identified.

M. Before excavation commences fill and pressurize the excavation chamber. The slurry shall then be circulated so that leakage from the seals, tunnel structure and surrounding ground can be investigated.

N. Excavation shall not start until after the slurry has been circulated through the slurry feed and discharge pipes and the slurry adjusting tank, and the condition of the slurry is suitable.

O. Check and monitor the wall thickness of all slurry pipes and pumps in the slurry transportation system at least monthly.

P. When extending the slurry feed and discharge pipes take appropriate measures to prevent slurry from being deposited within the tunnel or pit bottom.

Q. Experienced STP supplier staff shall thoroughly train all STP operators on the safe and effective operation and maintenance of the STP before the launch of the TBM and check lists shall be provided to ensure all aspects of the STP operation and maintenance are carried out.

R. The training provided shall reflect the complexity of the slurry tunneling system provide at site and all new operators shall undertake a period of closely supervised operation by an experienced technician for not less than 2 weeks.

S. Carry out pre-excavation laboratory testing to determine suitable face support medium (e.g. water and/or bentonite) for different ground conditions to determine viscosity and/or dosage.

T. Material separated at primary, secondary and final stages of separation in the STP shall be segregated prior to removal from site in bins to facilitate potential identification of a change in ground conditions.

U. Requirements for slurry operation with face pressure less than hydrostatic pressure:
   1. Pay detailed attention to potential dilution of slurry when operating the TBM below hydrostatic pressure.
   2. Design the slurry transportation system and pump capacity for water inflows based on operation of TBMs with face pressures below hydrostatic conditions. The system shall be designed for a groundwater inflow of 200 gpm at a minimum.
   3. Consider downhill tunneling and the tunnel gradient in the design of the maximum capacity of the slurry transportation system.
   4. Determine the maximum annular backfill grout pressure for when the TBM operates below hydrostatic pressure, including the design of mitigation measures where permeability and shunt flows are high.

5. Increase the face pressure as required if shunt flows are higher than limits in annular backfill grout mix design.
6. If tunneling with active face pressure below hydrostatic in the PAC geological formation or overburden soils between stations 95+00 and 88+00, inject Clay Shock using pressurized injection ports in the shield and/or tail skin while maintaining injection of backfill grout around the PCTL at all times.

V. Requirements for special slurry operational modes:
1. Mandatory zones for high viscosity bentonite support:
   a. Transition zones between different geotechnical units with minimum of 100 feet at the respective locations:
      1) Bois Blanc to St Ignace (~186+00).
      2) St Ignace to Pointe Aux Chenes (~164+00).
      3) Pointe Aux Chenes to St Ignace (~26+00).
   b. Zones with groundwater inflows greater than 200 gpm during TBM operation.
2. Mandatory zones for high density slurry support:
   a. TBM launching with shallow overburden and rock cover (207+90 to 203+00).
   b. Zones with low rock cover and close proximity to lakebed (203+00 to 184+00 and 0+90 to 0+00).

W. Requirements for squeezing ground conditions and overburden soils (if encountered):
1. If encountering ground conditions such as overburden soils or squeezing ground conditions commence injection of Clay Shock material until the entire TBM shield and tail skin are clear of the suspected limits of these ground conditions.
2. Inject Clay Shock into voids around the TBM using pressurized injection ports in the shield and/or tail skin while maintaining injection of backfill grout around the PCTL at all times.

3.5 SPOIL HANDLING, TREATMENT AND DISPOSAL

A. Dispose of excavated materials in accordance with Section 312326 “Reuse and Disposal of Excavated Materials”.

B. Make provisions for the handling and disposal of the drainage water from the muck in accordance with Section 312320 “Water Treatment and Disposal”.

3.6 CONTROL OF LINE AND LEVEL

A. Establish a secondary survey control system consisting of horizontal and vertical reference points for driving the tunnels and placing the PCTL.

B. Advance and verify all underground tunnel control so that the survey control is within 500 feet of the tunnel face.

3.7 ERECTION AND ASSEMBLY OF PRECAST CONCRETE TUNNEL LINING

A. Perform erection and assembly of the PCTL in accordance with the requirements of specification Section 317417 “Precast Concrete Tunnel Lining”, and the following.

B. Handle segments during transportation and erection processes so as to prevent damage.

C. Verify that the ringbuild area is free of water and debris so as to ensure proper placement and fit to the previous ring.

D. Verify that no damage has occurred to the segments and gaskets during transport and immediately prior to PCTL erection.

E. If all the thrust cylinder shoes on the key segment in the previous ring need to be removed to build the next ring, install key restraint system and confirm circumferential joint bolt is in place and fully tightened.

F. Inspect the seals of the vacuum lifting systems at regular intervals and replace them as required.

G. Ensure compression packers are properly positioned and attached, if used.

H. Erect rings within the protection of the TBM tail shield in the order and with the taper orientation required to follow the TBM. Ensure that construction of the tunnel is within the following tolerances:
   1. Departure of the tunnel from the indicated line or grade: max deviation of 3 inches vertically and 3 inches horizontally (6-inch diameter circular target).
   2. Maximum deviation from design diameter: plus or minus 1 inch.
   3. Maximum offset between adjacent segments at radial and circumferential joint ¼ inch on inside face.
   4. Maximum roll: 2.8 inches.
   5. Plane of lining: The leading edge of the PCTL shall not be out-of-plane by more than 0.2 inches.

I. Lubricate gaskets on the radial joints as needed to avoid the gasket being drug or forced out of the gasket groove during segment placement.

J. Ensure all segment joints faces are cleaned before connecting segments together. Check radial joints and clean as required so they are free from tail seal grease and other contaminants, and that gasket lubricant is not present on concrete surfaces.

K. Fully assemble segments such that concrete bearing surfaces are in intimate contact and gaskets in compression. Radial bolts shall be fully engaged but not torqued above the capacity of the bolt socket. Ensure circumferential connectors are fully engaged and will maintain gasket compression prior to releasing thrust cylinders.

L. Retighten all bolts prior to the restart of excavation operations and before the ring is clear of the tail skin.

M. Replace or repair segments sustaining damage during erection in accordance with Section 317417 “Precast Concrete Tunnel Lining”.

N. Do not utilize lifting/grouting sockets for temporary support of services in the tunnel unless specifically designed and checked for adequacy.

O. On completion of tunneling, wash PCTL to remove all foreign material with water and/or compressed air.

P. For each erected ring, complete an individual record survey of all relevant construction information and provide information in Segment Tracking Database.

3.8 TUNNEL BACKFILL GROUTING

A. Use a two-component grout system, with an accelerating admixture added and mixed at the point of injection through the tail skin grout ports for backfill grouting in accordance with Section 317117 “Backfill Grouting”.

B. Only use procedures that have been reviewed and accepted in the approved work plan and as specified in Section 317117 “Backfill Grouting”.

C. Perform verification of backfill grouting, and check grouting as required, in accordance with Section 317117 “Backfill Grouting”.

3.9 MONITORING AND CONTROL FOR PCTL

A. The ring measurements from the specified Ring Convergence Measurement system shall be used as primary means for monitoring dimensions and convergence of tunnel liner rings. Furthermore, visually monitor the dimensions and convergence elevations of the tunnel liner rings for convergence. If movement or distress of the PCTL is observed visually or with Ring Convergence Measurement system install convergence arrays using Excavation Monitoring Points in accordance with Section 310913 “Geotechnical Instrumentation and Monitoring”.

B. If the measurements indicate excessive movements are occurring, take corrective measures in accordance with submitted procedures. Consider ring deflection excessive if the diameter, measured between inside surfaces of the segments, changes by more than one inch from the diameter measured at the time of complete emergence from the TBM tail shield and completion of ring grouting.

C. If excessive deformations are occurring, take additional readings on affected sections of the liners once outside the range of the Ring Convergence Measurement system. Take readings daily, or more often if required, and after each shove of the shield, until deformations have shown no further movement over the period of one week.

D. Cease excavation and replace segments if damage to the PCTL exceeding the rejection criteria in Section 317416 “Precast Concrete Tunnel Lining” occurs within the first twelve inches of shove.

3.10 FREE AIR INTERVENTIONS

A. Propose suitable locations for free air interventions along tunnel alignment.

B. Minimum requirements for free air interventions:
   1. Slurry circuit design and dewatering system design to be able to cope with the anticipated water inflows for free air.
   2. Face stability to be checked by experienced geologist or experienced geotechnical engineer together with TBM Superintendent prior to entering the excavation chamber for tool inspection and changes, or other maintenance.

3. Continuous review (minimum every hour) of face stability by experienced geologist or experienced geotechnical engineer.
4. Install temporary video camera devices during free air interventions lasting longer than 4 hours to monitor face conditions at a minimum of two locations.

3.11 COMPRESSED AIR INTERVENTIONS

A. Compressed air working, compressed air plant, air locks and all other installations shall comply with the most stringent of all applicable local, State, and Federal regulations for working in compressed air. Where they do not conflict with these regulations, and as appropriate, apply the requirements and recommendations of EN 12110 "Tunnelling Machines, Air Locks, Safety requirements", ITA-AITES "Guidelines for Good Working Practice in High Pressure Compressed Air" and BTS "A Guide to Work in Compressed Air".

B. Install and commission the compressed air system prior to the launch of the TBM and demonstrate to the satisfaction of the Company that the compressed air facilities can be pressurized and access gained to the excavation chamber at 12 hours' notice without the need to bring in additional equipment from offsite.

C. Appoint a specialist provider of compressed air medical treatment and screening services to the acceptance of the Company.

D. No person shall be employed in any work in a compressed air environment unless they have undergone a training course which is designed to acquaint them with the hazards associated with work in compressed air.

E. All persons working in compressed air shall be certified as medically fit and medical certificates shall be available for inspection by the Company.

F. Provide each person who works in compressed air with a laminated identification card displaying name, photograph, employer, occupation, unique reference number and an emergency contact number that can be used in the event the person suffers from decompression sickness outside their hours of work. The ID card shall be surrendered on entry into the airlock.

G. All personnel operating plant and equipment for compressed air working shall be suitably qualified in line with requirements of this Section.

H. Record and submit all records for compressed air working and related works.

I. Keep a continuous record of the amount of low pressure air supplied to the working chamber, and the pressure in the working chamber.

J. Ensure that a sufficient number of workers are trained in rescue procedures, resuscitation, the use, care and limitations of breathing apparatus and the use and maintenance of firefighting equipment.

3.12 HYBERPARIC INTERVENTIONS (SATURATION WORKS) WITH SHUTTLE TRANSFER

A. Follow ITA "Guidelines for Good Working Practice in High Pressure Compressed Air".

B. Work in accordance with approved hyperbaric work plan.

C. Conduct training in mine rescue and safety necessary for hyperbaric work. Accommodate third party participation by the Company in training for hyperbaric work.

3.13 GEOTECHNICAL DATA COLLECTION

A. Maintain a log of a description of rock conditions, based on the character of tunnel spoil observed at the STP and during interventions.

B. Collect samples as follows:
   1. STP Samples:
      a. Observe spoil exiting the STP for changes in appearance. When a change in appearance is noted, or at a minimum frequency of once per day, or as otherwise directed by the Company, take a 0.5 cubic foot material sample from each of the discharge points at the STP.
      b. Place all material samples in a heavy duty watertight plastic bag, sealed, and identified by location and date. Samples shall be stored so as to prevent freezing of the samples and preserved for possible future examination and testing.
   2. Grab Samples:
      a. During each free air intervention, retrieve a 20-lb (minimum) grab sample from the tunnel face, having a preferred minimum dimension of 4-in x 4-in x 8-in. Samples shall be obtained from in-situ rock from the tunnel face wherever possible. If enough sample cannot be obtained from the tunnel face, rock blocks from within the working chamber are acceptable.
      b. During slurrifier box maintenance, retrieve a 20-lb (minimum) grab sample from material in the slurrifier box.
      c. Store each sample in a properly labelled 5 gallon bucket with tight fitting lid. The following information shall be provided on the bucket: “Project,” “Agreement No.”, “Tunnel Stationing,” “Date,” and any other necessary data requested by the Company.
      d. Store samples in a storage facility in accordance with specification Section 023200 “Geotechnical Investigations”.
   3. Laboratory testing requirements are not included in this specification. Perform laboratory testing as requested by the Company.

C. Groundwater Sampling:
   1. Collect groundwater samples during each intervention where representative groundwater can be collected. Allow at least 10 minutes of inflow to occur during intervention prior to collecting sample. Collect at least one sample per intervention event.
   2. Place groundwater samples in laboratory supplied sample containers, stored in a refrigerator or ice cooler, and ship under chain of custody protocol within the holding time for the selected analytes.
   3. Field measurements (using handheld meters to be approved by the Designer):
      a. pH.
      b. Temperature.
      c. Electrical conductivity.
      d. Dissolved oxygen (using an optical / luminescent meter).
   4. Laboratory analysis for:
      a. Total petroleum hydrocarbons by EPA Method 8015.

b. Volatile organic compounds (VOCs) by EPA Method 8260.
c. General water quality parameters:
    1) Alkalinity by EPA Method 310.1.
    2) Ammonia by EPA Method 350.3.
    3) Chloride by EPA Method 300.1.
    4) Calcium, Iron, Magnesium, Manganese, Sodium, Chloride, Sulfate by EPA Method 300.1.
    5) Fluoride by EPA Method 300.1.
    6) Nitrate by EPA Method 300.1.
    7) Phosphate (ortho) by EPA Method 300.1.
    8) Total Dissolved Solids by EPA Method 1601.
    9) Total Organic Carbon, by EPA Method 415.3.
d. Metals (Ag, As, Ba, Be, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, Ti, V, Zn) by EPA Method 6010.

5. Calibrate field meters prior to sample analysis and produce calibration record for each sampling event.

3.14 WATER LEAKAGE

A. Unless otherwise directed by the Company, undertake remedial measures to the completed PCTL as provided in Section 310179 “Sealing Leaks” if any of the following water inflows occur:
    1. More than 7000 gallons per day over the entire length of the bored tunnel.
    2. More than 0.7 gallons per minute per any 1000 linear feet of tunnel.
    3. More than 1 drip per minute at any location.
    4. Drips over the pipeline or where they have the potential to cause damage to equipment or malfunctioning of any electrical power.
    5. Water ingress causing the entry of soil particles into the tunnel.

B. At the Company’s sole discretion, the criteria in paragraphs A.1. and A.2. above may be increased.

3.15 TUNNEL SURVEYS: AS-BUILT PCTL SURVEY AND FINAL ALIGNMENT

A. After completing the tunnel drive, perform final as-built survey of the tunnel utilizing a closed traverse to establish accurate line, elevation, and stationing. This survey shall be submitted with as-built data compared with theoretical setting out data.

B. The As-Built surveys shall locate every tenth PCTL ring through the tunnel and the segments where the pipe support brackets are located. Where the survey shows that a section of tunnel is outside specified tolerances, survey shall be carried out at every ring throughout that section. This survey includes:
    1. Horizontal offsets from theoretical centerline to each inside face of tunnel.
    2. Vertical offsets to crown and invert measured from theoretical centerline.
    3. Four radial offsets through theoretical centerline measured at angles of 45 degrees from vertical.
    4. Measure horizontal stationing of points where measurements are taken, at the tunnel low point and at all other features as required by the Designer.
    5. Perform survey so that results may be entered directly into a computer program to check tunnel alignment.

C. For all measurements taken, calculate differences between actual and theoretical positions. Submit all information together with copies of a graphical representation of differences from theoretical.

3.16 CLEANUP

A. Before final handover of the tunnel, clean interior surface of the PCTL to be clean of any loose material, grout splatter, etc. and restore surface to a smooth, clean condition to satisfaction of the Company.

3.17 FIELD QUALITY CONTROL

A. At a minimum, include the following items in the Inspection and Test Plan:
   1. Surveillance:
      a. TBM assembly, retesting and recalibration.
      b. TBM operation.
      c. Segment erection.
      d. STP operation.
   2. Review:
      a. TBM and STP training records.
   3. Verification:
      a. TBM retesting and recalibration.
      b. Use of Clay Shock and steel shove plates when thrust forces exceed specified limits.
      c. Survey control.
      d. Data entry to Tunneling Monitoring and Documentation system.
      e. Data entry to Segment Tracking Database.
      f. Ring Convergence Measurements.
      g. As-Built Surveys.
   4. Witness Point:
      a. TBM retesting and recalibration.
      b. Tests on slurry.
      c. Damage and cleanliness check for segments and cleanliness of ring build area prior to erection.
      d. Installation of Key Restraint System.
   5. Hold Point:
      a. TBM launch and startup.
      b. Tunnel cleanup.

END OF SECTION 317119