SECTION 02425

TUNNEL EXCAVATION AND PRIMARY LINER

PART 1 GENERAL

1.01 SUMMARY

This Section includes:

A. Tunnel construction operation with primary lined tunnel installed during tunnel drive followed by placement of water line inside tunnel after completion of tunnel construction. This Specification is intended to be primarily functional in nature and to define in general terms Work to be accomplished.

B. Construction Methods: Various construction methods such as TBM, hand tunneling, or shield are allowed. Liners include rib and lagging, steel liner plate, bolted steel liner etc. Liners may be expanded or grouted.

1.02 MEASUREMENT AND PAYMENT

A. No separate payment will be made for Work performed under this Section such as excavation, liner, grouting, instrumentation, or monitoring. Include cost of tunnel excavation and primary liner in accordance with Section 02511 – "Water Lines".

B. Where such effort is necessary, cost for ground water control during course of tunnel work included in unit prices for water main in tunnel.

C. Ground water control required during course of Project to lower water table for other utility installation, to remove standing water, surface drainage seepage, or to protect ongoing Work against rising waters or floods considered incidental to Work being performed.

D. Stipulated Price (Lump Sum). If Contract is Stipulated Price Contract, payment for Work in this Section is included in Total Stipulated Price.

1.03 REFERENCES

A. The publications listed below form part of this specification to extent referenced. Publications are referred to in text by abbreviations only.

1. AREMA Manual for Railway Engineering (Applicable sections).

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

3. American Society for Testing and Materials (ASTM).

a. ASTM A36/A36M – Standard Specification for Carbon Structural Steel.

b. ASTM A1064/1064M – Standard Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete.

c. ASTM A283/A283M – Standard Specification for Low and Intermediate Tensile Strength Carbon Steel Plates.

d. ASTM A307 – Standard Specification for Carbon Steel Bolts, Studs, and Threaded Rod 60,000 PSI Tensile Strength.

e. ASTM A328/A328M – Standard Specification for Steel Sheet Piling.

f. ASTM A615/A615M – Standard Specification for Deformed and Plain Carbon–Steel Bars for Concrete Reinforcement.

g. ASTM C33/C33M – Standard Specification for Concrete Aggregates.

4. ASTM C150/C150M – Standard Specification for Portland Cement. American Water Works Association (AWWA)

a. AWWA C206 – Field Welding of Steel Water Pipe.

b. AWWA C200 – Steel Water Pipe, 6-inches and Larger.

5. Occupational Safety and Health Administration (OSHA): Particular attention is called to Subpart S of OSHA Standards (29 CFR 1926/1920), published as U.S. Department of Labor Publication 2207, Revised Oct. 1, 1979. Second revision dated August 1, 1989. See Federal Register dated June 2, 1989 for revised standard and commentary.

1.04 SUBMITTALS

A. Procedures: Conform to requirements of Section 01330 – "Submittal Procedures". Project Manager will review plans, details, and data for compliance with requirements of the Specification. Such review shall not be construed to relieve Contractor of responsibilities under Contract. Contractor shall not commence work on items requiring Contractor's work plan, construction drawings, or other submittals until submittals have been reviewed and accepted by Project Manager. All structural designs and other engineered components must be signed and sealed by Professional Engineer registered in the State of Texas.

B. Tunneling Work Plan: Submit to Project Manager for review, Tunneling Work Plan with complete construction drawings, complete written description identifying details of proposed method of construction and sequence of operations to be performed during construction, as required by method of tunnel excavation and liner installation. Submit sufficiently detail construction drawings and descriptions to demonstrate to

Project Manager whether proposed materials and procedures will meet requirements of Specification, as indicated below:

1. Submit Contractor's work plan and construction drawings on following items, depending on method of construction:

    a. If use of mechanized excavating equipment (such as TBM or shielded excavators) is proposed, submit arrangement drawings and technical specifications of machine and trailing equipment (including modifications), experience record with this type of machine of both Contractor and proposed operator and copy of manufacturer's operation manual for machine.

    b. The Contractor may elect to use tunnel shield that is separate from mechanized excavation equipment or for use with hand excavation. When use of tunnel shield is proposed, submit arrangement drawings, design criteria, dimensional data, and method of excavation and operation of shield, including acceptable method for supporting, controlling, and closing face of heading.

    c. Complete details of equipment, methods and procedures to be used for ground support, including but not limited to primary liner installation, timing of installation in relation to excavation plan, bulkheads and equipment.

    d. Grouting techniques meeting requirements this Section and Section 02431 – "Tunnel Grout".

    e. Procedures for measuring excavation quantities versus forward progress during tunneling operation (for earth pressure balance TBM only).

    f. Method of controlling line and grade of excavation.

    g. Details of muck removal, including equipment type, number, and disposal location.

    h. Description of ventilation system, lighting system, and electrical system.

    i. Proposed contingency plans for critical phases and areas of tunneling.

    j. Special activities at critical utility crossings, or for Work potentially affecting other facilities and existing utilities where special precautions must be taken during construction.

2. Submit design criteria established by Contractor's Engineer for primary liner, including design calculations and installation details, and certification by qualified Professional Engineer registered in the State of Texas that structural

design of primary tunnel meets criteria and specified requirements for range of field conditions.

3. Submit layout and design of proposed access shafts and shafts for permanent installations in accordance with Section 02400 – "Tunnel Shafts".

4. Submit ground water and surface water control system details per requirements in this Section and in accordance with Section 01578 – "Control of Ground Water and Surface Water".

5. All structural designs and other engineered items must be signed and sealed by qualified Professional Engineer Registered in the State of Texas unless otherwise specified.

C. Quality Control Methods: Submit description of quality control methods Contractor proposes to use in this operation to Project Manager. Include in submittal the following items:

1. Supervision: Supervisory control to ensure that Work is performed in accordance with Plans and Specifications and Contractor's work plan and construction drawings.

2. Line and Grade: Procedures for surveying, controlling, and checking line and grade, including field forms for establishing and checking line, and grade.

3. Tunneling Observation and Monitoring: Procedures for preparing and submitting daily logs of tunneling operations, including field forms, to meet requirement of Paragraphs 3.05, Tunneling Data and 3.06, Control of Tunnel Line and Grade of this Section.

4. Monitoring Instrumentation: Conform to requirements of Paragraph 3.08A, Monitoring Instrumentation of this Section.

5. Settlement Survey Plan, to meet requirements of Paragraph 3.08C, Settlement Surveying of this Section. This plan may be submitted as part of Instrumentation Monitoring Plan.

6. Building Condition/Assessment Plans: Conform to requirements of Paragraph 3.08B, Buildings and Structures Assessment of this Section.

D. Geotechnical and Environmental Investigation: Include results of geotechnical and environmental investigations performed by Contractor as relevant to tunneling in Work Plan. Submit these reports to the Project Manager for record purposes only.

E. Safety: Submit to Project Manager procedures to meet all applicable OSHA requirements including the following as minimum: Submit these procedures for record purpose only.

1. Protection against soil instability and ground water inflow.

2. Safety for shaft access and exit including ladders, stairs, walkways, and hoists.

3. Means of mechanical and hydraulic equipment operations, and for lifting and hoisting equipment and material.

4. Ventilation, lighting, and communication systems.

5. Monitoring for hazardous gases.

6. Protection against flooding.

7. Means for emergency evacuation.

8. Protection of shaft including traffic barriers, accidental or unauthorized entry, and falling objects.

9. Emergency protection equipment and self-rescue equipment.

10. Safety supervising responsibilities.

1.05 RELATED REQUIREMENTS

A. Section 01330 – "Submittal Procedures"

B. Section 01504 – "Temporary Facilities and Controls"

C. Section 01578 – "Control of Ground Water and Surface Water"

D. Section 02400 – "Tunnel Shafts"

E. Section 02431 – "Tunnel Grout"

F. Section 02511 – "Water Lines"

G. Section 02517 – "Water Line in Tunnels"

H. Section 02518 – "Steel Pipe and Fittings for Large Diameter Water Lines"

I. Section 02621 – "Geotextile"

J. Design Criteria

1. Design primary liner for appropriate loading conditions, including but not limited to: overburden and lateral earth pressures, handling and installation stresses, loads imposed by tunnel shield or tunnel boring machine thrust jacks, subsurface soil and water loads, grouting, and all other conditions of service. Contractor responsible for design of primary liner to carry thrust of jacking or

other construction forces or loads anticipated. Contractor's Professional Engineer is responsible for design of primary tunnel liner system.

2. At railroad crossings, unless otherwise specified by railroad authority use Cooper E-80 locomotive loading distribution criteria in accordance with AREMA specifications for culverts. Account for additive loadings for multiple tracks in design. Provide liner type for railroad crossings as specified or as otherwise required by railroad authority. Acceptable monitoring devices, such as closed circuit television, which permit continuous monitoring of conditions at face by qualified observers, from outside tunnel, may be used.

3. Use HS-20 vehicle loading distributions for truck loading criteria in accordance with AASHTO.

4. Compatibility of Methods:

   a. Use compatible methods of excavation, liner, and ground stabilization and ground water control.

   b. Design primary lining, when used to provide thrust for propulsion of shield, to withstand this thrust without damage or distortion. Configure propulsion jacks on shield so that thrust is uniformly distributed and will not damage or distort primary liner.

   c. Use compatible tunneling method with possible restrictions on Work, such as influence on existing installations or potential ground water contamination.

5. Demonstrate that chosen method will prevent flow of water or soil into tunnel and provide stability of face under anticipated conditions.

1.06 – 1.08 NOT USED

1.09 PROJECT SITE CONDITIONS

A. Safety Requirements:

1. Perform Work in manner to maximize safety and avoid exposure of men and equipment to hazardous and potentially hazardous conditions, in accordance with applicable safety standards and Contractor's safety procedures.

2. Whenever there is emergency or stoppage of Work which is likely to endanger tunnel excavation or adjacent structures, operate full work force for 24 hours a day, including weekends and holidays, without intermission until potentially hazardous conditions no longer exist or jeopardizes stability and safety of Work or existing installations.

3. Perform tunnel construction in a manner that shall minimize movement of ground in front and surrounding tunnel. Prevent significant subsidence of surface and protect structures and utilities above, and in vicinity of, tunnel from damage.

4. Support ground continuously in a manner to prevent loss of ground and keep perimeters and faces of tunnel and bottoms of shafts stable. Use filter-fabric and other means as necessary behind primary liner to prevent soil migration into tunnel.

B. Surveillance of Headings: When Contractor is not able to close face of machine because of maintenance requirements, maintain qualified personnel on duty to observe conditions that might threaten stability of heading whenever tunnel excavation is suspended or shut down. Equip personnel with approved contingency plan to take appropriate action to prevent or limit damage should conditions which threaten stability of heading occur.

C. Air Quality:

1. Conduct tunneling operations by methods and with equipment which shall positively control dust, fumes, vapors, gases, or other atmospheric impurities in accordance with OSHA, Federal, State, and City requirements.

2. Provide approved mining instrumentation for testing quality of tunnel atmosphere and obtain samples, under working conditions, at prescribed intervals in accordance with above referenced requirements. Submit results of air quality tests to Project Manager.

D. Ground Conditions: Perform sufficient exploration by geotechnical and environmental borings in advance of construction to define necessary parameters for design of primary tunnel liner, planning and designing ground water control system, and for selection of tunneling method and equipment to successfully complete each tunnel reach. Present results of Contractor's geotechnical and environmental investigations in related work plans.

1.10 DEFINITIONS

A. Tunneling Work Plan is defined as written description together with sketches, drawings, schedules, and other documents defining Contractor's planned methods and procedures for tunneling operations.

B. Contractor's Construction Drawings are defined as drawings by which Contractor proposes to furnish, construct, install, and operate referenced item.

C. Primary Liner is defined as Contractor's initial construction liner and tunnel support installed by Contractor for ground stability and safety during construction in

preparation for the installation of water line. Contractor chooses method of tunnel construction in accordance with this Specification. Inclusion of various methods in specification or reviews by Project Manager of Contractor's submittals shall not be construed by Contractor as endorsement by Project Manager that all such methods are constructible or will work for specific subsurface soils encountered.

D. Carrier Pipe is referred to as water line or permanent (secondary) liner. Such water line/permanent liner is defined and installed in accordance with Section 02517 – "Water Line in Tunnels" or Section 02511 – "Water Lines".

E. Tunnel Boring Machine (TBM): Mechanized and fully shielded excavating equipment that is steerable, guided and articulated, with man entry.

F. Shield: Fabricated ground support, circular in section, proving 360 degree protection to those working in it. Shield shall have cutting edge, and be equipped with independently operated hydraulic propulsion rams, allowing it to be steered. Liner is erected within tail attached to shield.

G. Open Face: Face of heading or tunnel which is unsupported during excavation (e.g., in hand mining or shield excavation).

H. Closed Face: Face of heading or tunnel which is supported during excavation process from TBM, where cutter head allows both partial exposure of face and full closure, by means of hydraulically operated gates.

1.11 – 1.13 NOT USED

PART 2 PRODUCTS

2.01 MANUFACTURER(S) (NOT USED)

2.02 MATERIALS AND/OR EQUIPMENT

A. Primary Tunnel Liner and Supports

1. The primary tunnel liner may consist of steel ribs and lagging, steel liner plates, precast concrete segments, steel casing pipe, or combinations of these. Lagging may be timber or steel. Box tunnels with timber supports will not be allowed. Utilize additional support elements including shotcrete, additional steel sets, breasting, spilling, forepoling, crown bars, soil anchors, or fabrics, as required to provide safe, stable excavation.

2. Use steel liner plates, steel casing, or steel lagging with steel ring beams as primary liner for tunneling under Texas Department of Transportation rights-of-way.

3. Use steel casing as primary liner for tunneling under railroad rights-of-way.

4. Use steel casing as primary liner for tunneling in fault zone crossings and when tunneling under drainage channels, creeks, bayous, and gullys.

B. Material Standards

1. Where use of following materials is required, conform to requirements of following minimum standards:

Material	**Reference Standards**
Cement	ASTM C150/C150M
Structural Concrete	
Reinforcing Steel Wire	ASTM A82 or A1064/A1064M
Reinforcing Steel Wire Fabric	ASTM A1064/A1064M
Reinforcing Steel Bars	ASTM A615/A615M , Grade 60
Sand and Aggregate	ASTM C33/C33M
Structural Steel	ASTM A36/A36M
Steel Piles, Sheets	ASTM A328
Rings and Ribs	ASTM A36/A36M
Steel Plates	ASTM A36/A36M and A283/A283M
Lumber and Timber	Hardwood, sound or better, as defined by Commercial Standard C560
Steel Casing Pipe	AWWA C200

C. Steel Liner Plates

1. Except as otherwise specified, furnish materials according to applicable requirements of AREMA Manual for Railway Engineering.

2. Bolts and nuts: Conform to ASTM A307, Grade A. Use bolts no less than 1/2 inch in diameter for plate gauge 7 or thinner and no less than 5/8 inch in diameter for greater plate thicknesses.

3. Punch plates for bolting on both longitudinal and circumferential seams and fabricate to permit complete erection from inside tunnel. Use plates of uniform fabrication and use interchangeable plates for those intended for one size tunnel.

4. Use new material for construction of liner plates. Used plates shall not be acceptable.

5. Provide steel liner plates manufactured by Contech Construction Products (2-flange), Commercial Pantex Sika, Inc. (4-flange), or approved equal, and

certified by manufacturer of compliance with specifications. Provide tensile strength, yield strength, and minimum elongation of liner plates. Also, provide design calculations for either 2-or 4-flange liner plates, as appropriate for Contractor's method of construction. All steel liner plate designs shall meet following minimum factors of safety:

Seam Strength.....3

Buckling 2

Maximum Deflection .....2% (of normal tunnel diameter)

6. Maintain minimum thickness of metal for these steel plates as shown on Plans, allowing for standard mill tolerances.

7. Equip steel liner plates with approximately 2-inch-diameter grout holes furnished with plugs. Locate holes near plate centers, such that when plates are installed there shall be one line of holes along crown and along each side of tunnel, not more than 18 inches above invert. Locate holes in each line at no more than every other plate and stagger.

8. Protective coating not required for steel liner plates, unless otherwise specified or shown on Plans.

9. Install gaskets between liner plates when required to control seepage, or as specified or shown in Plans.

10. Steel ribs used with liner plates: Conform to requirements of Paragraph 2.06, Steel Beams and Lagging.

D. Steel Casing Pipe

1. Casing pipe: Provide new uncoated welded steel pipe, manufactured in accordance with AWWA C200. Comply with Section 02518 – "Steel Pipe and Fittings for Large Diameter Water Lines".

2. Design stress in pipe wall shall be no greater than 50 percent of minimum yield point of steel or 18,000 psi, whichever is less when subjected to loading conditions.

3. Design deflection to be used in determining wall thickness shall not exceed 3 percent of nominal casing pipe size.

4. Bedding constant to be used in determining wall thickness shall be 0.10. Lag factors shall be 1.0 for all live loads.

5. Casing pipe design shall also include stresses due to jacking forces when pipe is to be installed by jacking method.

6. Equip casing pipe with approximately 2-inch diameter grout holes furnished with plugs. Place holes in pattern so that each succeeding hole from top dead center is 60 degrees right, then 60 degrees left, then top dead center. Locate holes in each line no more than 9 feet apart.

7. Conform casing pipe used in fault zones to welding and weld testing requirements specified in Section 02518 – "Steel Pipe and Fittings for Large Diameter Water Lines".

8. Casing pipe used in fault zones must be plugged at each end with clay bricks around O.D. of pipe minimum of one foot thickness measured into casing to prevent infiltration of soil into annular space.

E. Steel Ribs and Lagging

1. Steel ribs and auxiliary structural members shall be free of defects which may impair or reduce their structural integrity. Ribs shall be accurately curved to proper radius of tunnel section (or shaft section) and rib segments shall fit closely for bolted connections at segmental and transverse joints. Provide steel appurtenances required for installation of ribs such as tie rods, bolts, splice plates, dutchmen and drift pins, with ribs.

2. Minimum factors of safety:

a. Buckling 2

b. Stiffness 3

F. Timber

1. Use new timber for primary liner ground support without defects, of true dimensions and of quality grade and wood type defined by Contractor's Engineer.

G. Filter Fabric

See Section 02621 – "Geotextile" for requirements of material and minimum installation requirements. Install fabric, and backer rods, as required to prevent loss of fine-soil sediments into tunnel.

H. Equipment

1. Use only the tunneling method or equipment which shall produce specified results for soils encountered. However, use tunneling method, whether hand or machine, with full-face closure capabilities.

2. Diesel, electrical, hydraulic, or air-powered equipment is subject to applicable Federal and State regulations. Diesel engines equipped with scrubbers are

acceptable only when tunneling in free air with adequate ventilation. Provide compressed air and electricity for Contractor's operations from source outside tunnel.

3. When TBM is used, employ equipment that shall be capable of handling various anticipated ground conditions. In addition, TBM shall:

   a. Be capable of minimizing loss of ground ahead of and around machine and providing satisfactory support of excavated face. Use TBM with, when necessary for ground control, earth-pressure balance, or slurry-shield capabilities.

   b. Conform to shape of tunnel with uniform perimeter that is free of projections that could produce over-excavation or voids. TBM shield shall be continuous around its full perimeter; open-bottom shield is not acceptable.

   c. Have tail section long enough to enable setting of initial supports within machine, while still providing at least 12-inches of overlap beyond last installed support elements when thrusting jacks are extended to fullest extent possible.

   d. Have propulsion jacks capable of moving machine in forward direction while maintaining construction tolerances with respect to line and grade, without damage to previously-installed tunnel supports. Design propulsion system so that in event of failure of any element of system, there is no movement backward and there is no overstressing or distortion of tunnel supports.

   e. Incorporate seal in TBM tail shield to prevent leakage of grout between shield and liner into tunnel space, when grout is required immediately behind shield.

   f. Have motors and operating controls protected against water inflow.

   g. Provide bi-directional drive on cutter head wheel, or fins or grippers to control roll due to rotation.

   h. Provide means for maintaining tunnel face under wet and adverse soil conditions. Use closure doors on cutter wheel or other means, such as earth-pressure balance or slurry shield, acceptable to Project Manager.

4. When a tunnel shield is used (with or without attached mechanized excavating equipment), employ shield that shall be capable of handling various anticipated ground conditions. In addition, tunnel shield shall:

a. Conform to shape of tunnel with uniform perimeter that is free of projections that could produce over excavation or voids. Appropriately sized overcutting bead or taper along length of shield may be provided to facilitate steering. Shield shall be continuous around its full perimeter; open bottom shield is not acceptable. Although it is recognized that capability to over excavate beyond perimeter of shield may be necessary under certain conditions, make provisions to prevent accidental over excavation.

b. Have hood, poling or breasting plates, shelves and breast jacks, breast tables, and combinations of these and other bracing as necessary to fully support face of tunnel excavation without loss of ground.

c. Have tail section long enough to enable setting of initial supports within shield while still providing at least 12-inches of overlap beyond last-installed support elements when shield has been pushed forward to fullest extent possible.

d. Have propulsion system for moving shield in forward direction, while maintaining construction tolerances with respect to line and grade, without damage to previously-installed tunnel support. Design propulsion system so that in event of failure of any element of system, there is no movement backward and there is no overstressing or distortion of tunnel supports.

e. Have motors and operating controls protected against water inflow.

f. Incorporate seal in tail of shield to prevent leakage of grout between shield and liner into tunnel space, when grout is required immediately behind shield.

5. Air Quality: Provide equipment to adequately ventilate entire tunnel operation during construction, in accordance with OSHA requirements.

a. Provide portable testing equipment for carbon monoxide gas, hydrogen sulfide gas, oxygen deficiency, and explosive gases. Monitoring for other constituents may be required while tunneling in potentially contaminated areas as defined in Contractor’s safety plan.

b. Provide audible automatic gas alarm on TBM to detect explosive gases Locate alarm near tunnel face.

c. Equip motors and controls with automatic shutoff methane monitoring system.

6. Lighting: Provide adequate lighting with lights at 50 feet, maximum spacing in tunnel. Fixtures shall be in watertight enclosures with suitable guards. Provide separate circuits for lighting and for electrical equipment.

7. Electrical: Equip electrical systems utilized on TBM with appropriate ground fault system. Electrical systems are to be insulated, not permitting bare-wire exposures.

8. Access: Provide safe access through tunnel to TBM.

   a. Provide walkway in tunnels greater than 10 feet in diameter which is separate from tracks used by spoil removal equipment.

   b. Equip locomotives or cars used for transport of personnel with necessary safety devices.

9. Necessary equipment for tunnel excavation includes telephones, signal systems, fire extinguishers, safety equipment, and other equipment required by Contractor's method of construction, work plan, and safety plan. Maintain equipment in good repair, and readily available at place of work.

2.03 – 2.04 NOT USED

PART 3 EXECUTION

3.01 GENERAL / MANUFACTURER(S)

A. Use of various materials and construction methods for tunnel excavation and ground support, such as by tunnel boring machine (TBM), hand tunneling or shield will be allowed provided that proposed products and methods will complete Project in accordance with Specifications, this Section, applicable safety codes, and Project schedules. Contractor responsible for final constructed product, materials and tools used, and for furnishing labor and qualified superintendents necessary for selected method of construction.

B. Use tunnel liner or casing of a size so that minimum clearance at the bottom between O.D. of carrier pipe and inside of liner is minimum 4 inches, and minimum clearance at the top between O.D. of pipe and inside of liner or casing is in accordance with following:

Carrier Pipe Net I.D.	Minimum Clearance to Top
≥ 48"	9"
42"	7"
36"	5"
≤ 30"	3"

C. This clearance also applies to distance between carrier pipe and electrical conducting pipe support system.

D. Furnish all items, such as TBM or shield with excavation equipment, spoil disposal systems, muck trains, hoist, grouting, signal systems, ventilation, safety equipment, and survey controls necessary to excavate and advance tunnel and construct primary tunnel liner by selected method.

3.02 PREPARATION

A. Contractor shall be responsible for his means and methods of tunneling construction and shall ensure safety of Work, Contractor's employees, public, and adjacent property, whether public or private.

B. Execute Work of excavating, lining, grouting, and construction of tunnel so that ground settlement or loss will be minimized. Completed primary tunnel lining shall have full bearing against earth with no voids or pockets left in Work. Fill peripheral space between support elements and excavated surface no less frequently than after each shore or close by expanding support elements against ground as shield advances. Provide stability of face under anticipated conditions.

C. Maintain clean working conditions inside tunnel and remove muck, debris, material spills, unusable supports, and other material not required for tunneling.

D. Be aware that various existing soil borings, piezometers, or instrument wells may coincide with proposed tunnel alignment. These may or may not have been backfilled with grout and therefore caution should be used in tunneling through these existing borings. Take mitigating measures to counter effect these boreholes, piezometers, or instrument wells may have on tunneling operations.

E. Perform tunneling under railroad embankments, highways, or streets to prevent interference with operation of railroad, highways, or streets.

F. Do not perform any surface activities pertaining to water line construction within a tunnel area unless otherwise approved by Project Manager.

G. Conduct tunneling operations in accordance with applicable safety rules and regulations, OSHA Standards, and Contractor's Safety Plan.

H. Perform additional exploration of ground conditions by geotech borings if needed to define necessary parameters for design and for selection of tunneling method. No additional pay.

3.03 ERECTION/INSTALLATION APPLICATION AND/OR CONSTRUCTION

A. Tunnel Excavation and Primary Liner Installation

1. Tunnel Excavation:

a. The selected method of tunnel excavation is subject to review by the Project Manager.

b. Conduct tunneling operations in accordance with applicable safety rules and regulations, and Contractor's safety plan. Use methods which include due regard for safety of workmen, adjacent structures, utilities, and public.

c. Limit tunnel excavation to within easements and rights-of-way indicated on Plans, and to lines and grades designated on Plans. Perform excavation of sufficient size to allow installation of water line to lines and grades indicated on Plans.

d. Locate equipment powered by combustible fuels at suitable distances from shafts to prevent possibility of explosion and fire in shafts or tunnel.

e. During open-face excavation:

1) Excavate face commencing at crown and proceed down to invert. Excavate both sides of heading simultaneously. Keep hood buried in soil ahead where soils include sands and silts.

2) Keep face breasted or otherwise supported; employ other means as necessary to maintain face stability and prevent falls, excessive ravelling, or erosion. Maintain standby face supports for immediate use when needed.

3) During shut-down periods, support face of excavation by positive means; do not rely solely on hydraulic pressure for support. When face is untouched for more than 24 hours, and when required by Project Manager, fully breast face and shove shield tight against it.

f. During closed-face excavation:

1) Carefully control and monitor volume of spoil removed. For earth-pressure balance TBM, balance spoil removed with advance rate and excavation rate.

2) When cutting face is withdrawn, keep excavated face stabilized as required.

g. Advancing Shield: During forward movement of shield, provide sufficient support at excavation face to prevent movement of materials except materials as are physically displaced by elements of shield itself. Excavation shall not be advanced beyond the edge of the shield.

2. Size of Tunnel: Determine adequate tunnel size and section to match construction methods described in work plan. Build tunnels of sufficient size to permit efficient excavation operations, to provide sufficient working space for placing primary tunnel liner, and to allow for installation of water line as shown on Plans or indicated in Specifications. Dimensions shown on Plans do not necessarily represent size or section suitable for construction methods or operational procedures as may be proposed or conducted by Contractor.

3. Primary Liner:

a. Provide primary liner for tunnel which is capable of supporting ground and hydrostatic forces until permanent water pipe has been installed and grouted in place, and to resist construction loads.

b. Use methods that ensure full bearing of soil against primary liner without significant settlement or movement of surrounding soil. To fill void behind primary liner, either expandable liner (e.g., ring beams and timber lagging) or nonexpandable liner (e.g., bolted steel liner plates) may be used provided grout is placed behind nonexpandable liner. Grout excavation not to true shape as result of careless excavation or loss of ground.

c. The primary liner's seepage inflow for each 100-foot length of tunnel shall not exceed 3 gallons per minute, including inflow through face or shield. Localized inflow shall not exceed 0.5 gallons per minute. Provide drainage facilities to remove inflow of water from tunnels and shafts. Provide means to prevent inflow of soil fines associated with water inflow by use of filter fabrics or other approved methods.

d. Expandable liner shall be continuous and shall be expanded to limits of excavation promptly after it is out of shield.

e. During excavation of tunnel, advance TBM or shield only far enough to permit construction of one primary liner ring beam set, or rings of

bolted steel liner plates that can be assembled entirely within tail shield of TBM.

f. Install filter fabric around exterior of primary liner when using non-watertight liner and when tunneling through sandy or silty ground conditions. Install backer rods at ribs as required to control migration of fines. Close windows in lagging.

g. Provide hog rods, struts, or similar members when required to maintain roundness. After grouting, liner shall be no more than 3 percent out of round as measured by difference between maximum and minimum measured diameter divided by average diameter.

4. Hand Jacking of Casing:

a. Provide heavy-duty jacks of capacity suitable for forcing casing pipe through ground. Construct operating jacks so that even pressure is applied to all jacks used. Provide suitable jacking head, (timber, etc.), and suitable bracing between jacks and jacking head. Provide suitable jacking frame and/or back stop. Set casing pipe to be jacked on guides, (timber, etc.), properly braced together, to support section of pipe, and direct it to proper line and grade. Place whole jacking assembly so as to line up with direction and grade of casing pipe.

b. Excavate ground material just ahead of casing pipe by use of air-powered tools, excavating machine, or other acceptable means, and remove through casing pipe. Then force casing pipe through ground with jacks, into space thus provided. Dispose excavated material as specified.

c. Trim excavation in manner so that at least one third of circumference of excavation conforms to contour and grade of casing pipe. Provide clearance of not more than 2 inches for upper half of casing pipe with clearance tapering off to zero at point where excavation conforms to contour of casing pipe. Cutting edge of steel plate installed around head end of casing pipe extending short distance beyond end of casing pipe with inside angles or lugs to keep cutting edge from slipping back onto casing pipe may be used.

d. In addition to requirements set for in this specification, Contractor shall:

1) Excavate face commencing at crown and proceed down to invert. Excavate heading so that both sides of heading are excavated simultaneously.

2) At all times maintain standby face supports to allow for immediate use when needed.

3) At end of each shift and whenever excavation is suspended or shut down, install breast boards, or other approved methods, across full face of heading.

e. Distance that excavation extends beyond end of casing pipe shall not exceed three feet. Decrease this distance as directed by Project Manager, or due to character of material being excavated.

f. Jack the casing pipe, insofar as practical, from low or downstream end. Lateral or vertical variation in final position of casing pipe from line and grade as established by Project Manager will be permitted only to extent of 1 inch in 10 feet, provided that variation is regular and only in one direction and that final grade of flow line is in direction indicated on plans. Remedy overcutting by pressure grouting entire length of installation. Use of grout mix immediately behind shield tail shall have efficient tail seal to prevent flow of grout into shield.

g. Depending on character of soil encountered during jacking operation, carry on operation without interruption, insofar as practical, to prevent casing pipe from becoming firmly set in ground.

h. Remove and replace casing pipe damaged in jacking operations by Contractor at no additional cost to Owner.

i. Backfill pits or trenches which have been excavated to aid jacking operations as soon as casing pipe is complete in place, equipment and appurtenances have been removed and structure, which is to be built in excavated zone, is in place. In no case shall pits remain open without appropriate safety barricades, concrete traffic barriers (CTB's), railing, or plates.

j. When jacking casing pipe, water jetting of casing pipe bedding or backfill is not allowed. In unconsolidated soil formations, use gel-forming colloidal drilling fluid consisting of at least 10 percent of high grade fully hydrated bentonite to seal voids outside walls and furnish lubrication for installation of casing pipe.

5. Grouting:

a. Detailed requirements pertaining to grout mix design and tunnel grouting are provided in Section 02431 – “Tunnel Grout”.

b. Furnish and operate suitable equipment for grouting operations to effectively and completely fill voids outside of primary tunnel liner as quickly as possible.

c. Provide in tunneling work plan description of primary liner grouting operations, including:

1) Arrangement of grouting equipment including mixer, pumps, piping and hoses, valves, pressure gauges and injection fixtures.

2) Location, spacing, and size of grout ports and vents.

3) Grouting sequence for initial backfill of voids between liner and ground, and for second stage back grouting.

4) Grout injection pressures and estimated volumes.

5) Procedure to check for remaining voids.

6) Sampling procedures and locations for quality control testing.

7) Grout production and quality shall be in accordance with Contractor's mix design and grout production plan as required by Section 02431 – "Tunnel Grout".

d. Use care in grouting operations to prevent damage to adjacent utilities or other properties. Ensure that pressure used in grouting is not great enough to distort or imperil Work.

e. Fill voids behind non-expandable primary liner with sand-cement grout promptly after liner is out of shield. Grout pressure shall not exceed value that may cause damage or distortion to installed liner plate rings. Grout from bottom up and plug each grout hole promptly after grout has been placed. Provide seals on tail of TBM which will prevent grout from moving into shield.

f. Liner requiring grout shall be back grouted (second stage grouting) once each shift, or more often when required to ensure that all voids are filled.

g. Place grout behind tunnel liner at end of each day or at every 4 feet of tunnel installed, whichever is less, unless in opinion of Project Manager, ground conditions are such as to require each ring to be grouted immediately after erection. Upon completion of each grouting operation, sound primary liner and immediately correct voids discovered by necessary means as approved by Project Manager. After all voids are successfully filled, grout holes shall be packed, when

necessary, with dry mortar mix and threaded taps securely placed in holes.

h. Completely and immediately fill voids outside limits of tunnel excavation created by caving or collapse of earth cover over excavation, or by other cause, with sand cement grout. Perform second grouting to fill soft spots or voids which may be detected, no later than 24 hours after initial grouting of primary liner.

i. Perform quality control sampling and testing of grout.

1) Grout production shall be in accordance with Section 02431 – "Tunnel Grout".

2) Measure density of grout throughout placement procedure as directed by Project Manager. Measure grout density at discharge point and discharge grout until density is within 0.3 pounds per gallon of input density.

3) Take samples of well-mixed grout for 28-day compressive strength tests at beginning, middle, and end of each grouting operation.

B. Tunneling Data

1. Submit shift logs of construction events and observations within 24 hours of operation on at least following:

a. Location of face by station and progress of tunnel drive during shift.

b. Observation of lost ground and other signs of ground movement.

c. Location and elevation of significant soil strata boundaries and brief soil descriptions.

d. Ground water control operations, piezometric levels, ground water inflow location, and rates.

e. Completed field forms for establishing and checking line and grade and achieved tolerance relative to design alignment.

f. Operation shut-down periods or other interruptions in Work, and reason.

g. Any unusual condition or event.

h. Hours worked per shift on tunneling operation.

2. Clearly mark primary liner every 20 feet along tunnel with distance in feet from centerline of preceding shaft.

C. Tunnel Connections, Terminations, and Temporary Bulkheads

1. Connect new tunnels to existing structures by removing existing bulkheads, when necessary, and sealing junction as shown on Plans.

2. Seal terminations of tunnels, which are not connected to permanent structures, by temporary bulkhead.

3. Design temporary bulkheads where and when required and obtain Project Manager's acceptance of design prior to constructing it. Provide bulkheads capable of resisting lateral earth and hydrostatic pressures, waterproof, and capable of being removed without damaging water line or plastic liner.

D. Monitoring

1. Monitoring Instrumentation: This specification establishes minimum instrumentation requirements for tunneling. Additional instrumentation requirements for critical areas may be specified elsewhere in Specifications or on Plans. Contractor may install more extensive system at Contractor’s sole expense. Instrumentation specified shall be accessible at all times to Project Manager.

a. Submit for review, prior to construction, Monitoring Plan including instrument installation design, instrumentation points location and layout, manufacturer's catalog literature, installation report formats.

b. Install and maintain system of instrumentation to monitor tunneling operation and to detect movement in soil and adjacent structures. Instruments shall consist of no less than sufficient number of inclinometers and crack monitors at bridge and adjacent structures and sufficient piezometers. Use monuments sufficiently removed from construction to avoid errors in readings due to ground settlement.

c. Installation of instrumentation by Contractor shall not preclude Project Manager, through independent contractor or consultant, from installing instrumentation in, on, near, or adjacent to construction work. Provide access to work for independent installations.

d. Install soil instruments such as piezometers, inclinometers, extensometers, and crack monitors by qualified subcontractor specializing in geotechnical work.

e. Install extensometers to depth of 5 feet above crown of water line tunnel as shown on Plans to measure vertical movements in soils during and subsequent to tunneling. Extensometer consists typically of three-prong anchor, 1/4-inch standard stainless steel inner pipe, and 1-inch standard Schedule 80 PVC outer pipe. Pipes are assembled in sections

and fastened together with standard couplings to required anchor depths. Locate top of extensometer within flush-mounted hand hole cover capable of withstanding HS-20 truck loading. Geotechnical instrumentation installation subcontractor shall provide procedures for installation of extensometers as part of Monitoring Plan.

2. Building and Structures Assessment: Submit for review prior to construction, Building and Structures Assessment Plan. Provide preconstruction and post-construction assessment reports for buildings and structures located within distance equal to depth of tunnel but at least 50 feet in plan from proposed tunnel centerline and shafts. Include photographs or video of existing damage to structures in vicinity of water line alignment in assessment reports.

3. Settlement Surveying: This specification establishes minimum settlement survey requirements for structures and ground surface monitoring points.

   a. Submit settlement surveying and monitoring plan for review prior to construction. Plan shall identify location of settlement monitoring points, reference benchmarks, survey schedules and procedures and reporting formats.

   b. Locate survey points on all structures within distance equal to depth of tunnel but at least 50 feet in plan from tunnel centerline.

   c. Record horizontal coordinates and elevations (with accuracy of 0.01 feet) for each survey point location. Reference survey points so that they may be accurately reestablished when lost or destroyed.

   d. Unless otherwise specified, record ground surface elevations on center line ahead of TBM and at 20 feet either side of center line at minimum of 100-foot intervals or at least three locations per tunnel drive. Starting 100 feet ahead of TBM and continuing until TBM is 100 feet beyond measurement point or until further movement is not detected, unless otherwise directed by Project Manager. Record cross-sectional points at 10-foot spacing for distance of 50 feet each side of center line or to ROW, whichever is less.

   e. Locate survey points at crossings under installations as follows:

      1) Roads: Centerline and each shoulder.

      2) Railroads: Track subbase at centerline of each track.

      3) Utilities and Pipelines: Directly above and 10 feet before and after intersection.

   f. For shaft settlement see Section 02400 – “Tunnel Shafts”.

4. Measure and maintain records of deformation of primary liner.

5. Reading Schedule and Reporting: Submit readings from various instruments and survey points weekly to Project Manager. Take daily Readings as required by Project Manager when construction is approaching or near critical structures (structures, bridge piers, pipelines, etc., partially or entirely located within distance equal to depth of tunnel but at least 50 feet in plan from tunnel centerline). Take initial readings of surface points before excavation or construction is started.

   a. Immediately report to Project Manager movement, cracking, or settlement which is detected and take immediate remedial action. Contractor shall be fully responsible for damage to adjacent structures.

   b. At end of construction after water line is installed, and dewatering is discontinued, make final survey of control points established for instrumentation and observation. Submit final readings to Project Manager. Make visual inspection of structures adjacent to water line and report to Project Manager condition of structures, damage incurred during construction, and corrective action taken.

E. Disposal of Excess Material

Remove spoil from job site and dispose in accordance with Section 01504 – "Temporary Facilities and Controls".

3.04 REPAIR/RESTORATION (NOT USED)

3.05 FIELD QUALITY CONTROL

A. Control of Tunnel Line and Grade

1. Construction Control:

   a. The Project Manager will establish baseline and benchmarks indicated on Plans. Check these baseline and benchmarks at beginning of Work and report errors or discrepancies to Project Manager.

   b. Use baseline and benchmarks established by Project Manager to furnish and maintain reference lines and grades for construction. Use these lines and grades to establish location of tunnel, water line, and structures.

   c. Establish and be fully responsible for accuracy of controls for construction of Project, including access shaft locations, structures, tunnel line, and grade. Utilize laser to insure line and grade are maintained during tunneling process.

d. Establish control points sufficiently removed from tunnel operation not to be affected by potential ground movement.

e. Maintain daily surveying records of alignment and grade and submit three copies of records to Project Manager by end of day after Work performed. Locate points at top, bottom, and each side of springline.

f. Check tunnel survey control against aboveground undisturbed reference at least once each week and once for each 250 feet of tunnel constructed, or more often as needed or directed by Project Manager.

2. Earth Movement: Contractor is responsible for damages due to settlement from construction-induced activities or occurrences.

a. Take precautions to avoid damage or settlement to buildings, structures, roads, and utilities to work in proximity of tunnel. Minimum precautions to include use of construction methods and equipment to minimize loss of earth at tunnel face and settlement of soil around primary tunnel liner.

b. Refer to Paragraph 3.08, Monitoring, for detecting earth movement.

c. In event movement of ground is detected, Project Manager may order work stopped and secured. Before proceeding, correct problems causing or resulting from movement.

d. Be aware that when settlement of ground surface should occur during construction of tunnel which will affect accuracy of temporary benchmarks established by Project Manager, detect and report movement. Locations of permanent NHCRWA monumentation benchmarks are indicated on Plans; Contractor may use these to verify temporary benchmark accuracy. Advise Project Manager of settlement affecting permanent monumentation benchmarks. Upon completion, submit field books pertaining to monitoring of permanent monumentation benchmarks to Project Manager.

3. Tunnel Line and Grade:

a. Survey crown, invert, and spring line on each side of primary liner at 50-foot intervals, or minimum of once per shift, or more frequently when line and grade tolerances have been exceeded, to ensure alignment is within tolerances specified. Conduct survey immediately behind tunnel excavation to allow immediate correction of misalignment.

b. Control excavation of tunnel and construction of primary liner to allow construction of carrier pipe within 6 inches on line and 4 inches on grade and to maintain circular shape of tunnel.

c. Alignment adjustments between primary tunnel liner and water main shall not encroach on minimum required clearance of 4 inches defined in Section 02517 – "Water Line in Tunnels".

d. If unable to maintain specified tolerances, bear full responsibility and expense of correction (redesign, easement acquisition, etc.). When these tolerances are exceeded and redesign of structures is required, obtain services of qualified Professional Engineer registered in the State of Texas for redesign. Submit plans showing changes to Project Manager for review.

e. Backfill (grout) and reconstruct tunnel built outside tolerance to be within tolerance when so directed by Project Manager.

B. Ground and Surface Water Control and Ground Stabilization

1. Provide necessary ground water and surface water control measures to perform Work and to provide safe working conditions. Detailed plans for ground and surface water control methods shall be executed as designed by the Contractor's Engineer. Prevent excessive inflow of water into excavation during construction of tunnel and installation of carrier pipe and grouting of annular space. Ground water control method shall provide means to prevent piping of fines into shafts or tunnel and other adverse effects due to ground water inflow. Surface water control method shall provide means to control impacts of surface water above or along tunneling operations. Additional requirements are included in Section 01578 – "Control of Ground Water and Surface Water".

2. Anticipate that portions of tunnel excavation may be below ground water table and in cohesionless soils, even when not indicated on soil borings, and in conditions which may require ground water control system for tunneling operations. Install filter fabrics, backer-rods and other means as necessary to prevent piping of fines into tunnel. Remove water that may be encountered during course of Work by pumping, well pointing, deep well pumping, or other means determined by Contractor as necessary to achieve stable conditions and applied in manner as described in Section 01578 – "Control of Ground Water and Surface Water". Standing water is not permitted at face or in tunnel.

3. The ground water control method used shall not cause damage to adjacent structures or property due to lowering of water table and subsequent ground settlement. In event damage does occur, correct damage and settle claims arising from damage at no additional cost.

4. If Contractor chooses pumping installations to control ground water level or installs pervious liner through water bearing layers, install and maintain instrumentation system to monitor water level and to detect movement in adjacent structures and property. Monitor water level by recording initial water level before dewatering is started and thereafter on weekly basis. Remove water monthly from piezometers to demonstrate that they are operable. Submit weekly reports of water levels to Project Manager. Provide access to piezometers for Project Manager to perform independent measurements.

5. Maintain dewatering system for tunnels in continuous operation until minimum of 48 hours after carrier pipe has been installed and annular space is fully grouted, or until watertight liner designed for hydrostatic pressures is installed.

6. If eductors, well points, or deep wells are used, space them adequately to provide necessary dewatering. Use sand packing, and other means to prevent pumping of fine sands or silts from subsurface and to minimize ground subsidence. Check continuously to ensure that subsurface soil is not being removed by ground water control operation or subsurface drainage into shafts or through pervious liner. Before operations begin, maintain availability of pumping equipment and other machinery on site to assure that operation of dewatering system can be maintained.

7. When groundwater control is necessary, do not begin tunneling operations until monitoring data shows that it is safe to do so. When dewatering is sole means of ground water control, draw piezometric level at least down below elevation of invert of tunnel, or to lower elevation as required for excavation face and tunnel stability.

3.06 – 3.10 NOT USED

END OF SECTION