SPECIAL SPECIFICATION

1169

Tunnel Excavation and Primary Liner For Water Mains

1. Description. This Item consists of tunnel construction and installation of primary liner to be installed during the tunnel drive. Following installation of the primary lining, the final water line is to be installed. This Specification is to define in general terms work to be accomplished.


   (1) General.

       (a) The use of a closed, pressurized face tunnel boring machine (TBM) is required to excavate the tunnel and install primary ground support

       The Contractor's Professional Engineer is responsible for design of primary tunnel liner system.

       The Contractor is responsible for the final constructed product, materials and tools used, and for furnishing labor and qualified superintendents necessary for construction.

       Employ a TBM 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.

   (2) Reference Standards. Where use of following materials is required, conform to requirements of following minimum standards:

       | Material            | Reference Standards          |
       |---------------------|-----------------------------|
       | Structural Steel    | ASTM A36                    |
       | Steel Piles, Sheets | ASTM A328                   |
       | Lumber and Timber   | Hardwood, sound or better, as defined by Commercial Standard C560 |
       | Steel Casing Pipe   | AWWA C200                   |


   (3) Liner and Supports.

       (a) The primary tunnel liner will consist of steel casing pipe.
(4) **Steel Casing Pipe.**

(a) Casing pipe: Provide new uncoated welded steel pipe, manufactured in accordance with AWWA C200.

(b) Design stress in pipe wall shall be 50% of minimum yield point of steel or 18,000 psi, whichever is less when subjected to loading conditions.

(c) Design deflection to be used in determining wall thickness shall not exceed 3% of nominal casing pipe size.

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

(e) Minimum thickness of steel casing shall be as shown on drawing.

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

(g) Equip casing pipe with approximately 2-in. 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 ft. apart.

(5) **Filter Fabric.** Fabric materials shall meet the requirements of Departmental Materials Specification D-9-6230, "Temporary Sediment Control Fence Fabric". Install fabric, and backer rods, as required to prevent loss of fine-soil sediments into tunnel.

(6) **Grout.** Grout for pressure grouting, backfill grouting and annular grouting shall consist of a sand-cement mortar.

(a) Employ and pay for a commercial testing laboratory, acceptable to the Engineer, to prepare and test the grout mix design. Develop one or more mixes based on the following criteria as applicable:

- Size of annular void between primary liner and surrounding soil
- Absence or presence of groundwater
- Adequate retardation
- Non-shrink characteristics
- Pumping distances

(b) Prepare mixes that satisfy the required application(s). Provide materials conforming to the following standards:

- Cement: ASTM C 150
- Fly Ash: ASTM C 618
Water: Potable

Sand for sand-cement mortar mix: ASTM C 144

(c) Provide grout that meets the following minimum requirements:

Minimum 28-day unconfined compressive strength: 1500 psi

Determine strength by ASTM C 942

Maximum allowable density: Less than 130 pcf

(d) Fluidifier. Provide fluidifier, meeting ASTM C 937 that holds solid constituents of grout in colloidal suspension and is compatible with cement and water used in grouting operations.

(e) Admixtures.

Use admixtures meeting ASTM C 494 and ASTM C 1017 as required, to improve pumpability, control time of set, hold sand in suspension and reduce segregation and bleeding.

Ensure that admixtures used in the mix are compatible. Provide a written confirmation from the admixture manufacturers of their compatibility.

3. Definitions.

(1) The Tunneling Work Plan is defined as written a description together with sketches, drawings, schedules, and other documents defining the Contractor's planned methods and procedures to construct specified item. The Contractor's Construction Drawings are defined as drawings by which the Contractor proposes to furnish, construct, and install, the referenced item. Submission of Tunneling Work Plans, including construction drawings, is required to provide the Engineer with sufficient details to verify that the Contractor's planned work and work in progress is in accordance with the intent of design and specification requirements.

(2) The Primary Liner is defined as the Contractor's initial construction liner and tunnel support installed to stabilize the ground safely during construction in preparation for installation of the water line.

(3) Carrier Pipe is referred to as water line. Water line is defined and installed in accordance with Special Specification, Water Mains.


(1) Review: The Engineer will review submitted plans, details and data for compliance with the requirements of this Specification. Such review shall not be construed to relieve the Contractor of responsibilities under the Contract. The Contractor shall not commence work on items requiring the Contractor's work plan, construction drawings or other submittals until such submittals have been reviewed and accepted by the Engineer. All structural designs and other engineered components shall be signed and sealed by Professional Engineer registered in the State of Texas.
(2) Tunneling: Submit for review the Tunneling Work Plan with complete construction drawings, a complete written description identifying details of proposed method of construction, and a sequence of operations to be performed during construction. Sufficiently detail construction drawings and descriptions detailed to demonstrate to the Engineer whether the proposed materials and procedures will meet the requirements of the Specification.

(a) Submit Tunneling Work Plan and construction drawings on the following items:

Arrangement drawings and technical specifications of machine and trailing equipment (including any modifications), experience record with this type of machine of both the Contractor and the proposed operator for the machine.

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

Procedures for measuring excavation quantities versus the forward progress of the machine during the tunneling operation.

Methods of controlling line and grade of the excavation.

Details of muck removal, including equipment type, number and disposal location(s).

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

Proposed contingency plans for critical phases and areas of tunneling.

(b) Submit for review the design criteria established by Contractor's Engineer for the primary liner, including design calculations and installation details.

(c) Include in Tunneling Work Plan special activities at critical utility crossings, or for work potentially affecting other facilities and existing installations, where special precautions must be taken during construction.

(d) Submit for review a layout and design of proposed access shafts and shafts for permanent installations. Clearly indicate allowable surcharge loads and restriction on surcharge capacity, including live loads, on shaft construction drawings. Indicate thrust blocks or other reactions required for pipe jacking, when applicable.

(e) Submit ground water control system per requirements in this specification.

(f) Submit description of materials, grout mix, equipment and operational procedures to accomplish each grouting operation. The description may include sketches as appropriate, indicating the type and location of the mixing equipment, pumps, injection points, venting method, flow lines, pressure measurement, volume measurement, grouting sequence, schedule, and stage volumes. Tests and certifications shall have been performed within the last 12 months prior to the date of the submittal.
(g) Submit grout mix design report, including:

- Grout type and designation
- Grout mix constituents and proportions, including materials by weight and volume
- Grout densities and viscosities, including wet density at the point of placement
- Initial set time of the grout
- Bleeding, shrinkage/expansion
- Compressive strength
- A detailed description of grout pressure limiting equipment

(h) Provide in the Tunneling Work Plan a description of the primary liner grouting operations, including:

- Arrangement of the grouting equipment including mixer, pumps, piping and hoses, valves, pressure gauges and injection fixtures.
- The location, spacing and size of the grout ports and vents.
- The grouting sequence for the backfill of the voids between the liner and the ground.
- Grout injection pressures and estimated volumes.
- Procedure to check for remaining voids.
- Sampling procedures and locations for quality control testing.

(3) Quality Control Methods. At least 30 days prior to start of tunneling, submit a description of quality control methods the Contractor proposes to use in this operation to the Engineer. Include in submittal:

(a) Supervision: Supervisory control to ensure that work is performed in accordance with the Drawings and Specifications and the Contractor's work plan and construction drawings.

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

(c) Tunneling Observation and Monitoring: Procedures for preparing and submitting daily logs of tunneling operations, including field forms, to meet the requirement of Paragraphs 6(9), Tunneling Data and Paragraph 6(10), Control of Tunnel Line and Grade.

(d) Monitoring Instrumentation: Submit the Monitoring Plan including the instrument installation design, instrumentation points location and layout, manufacturer's
catalog literature, and installation report formats. Conform to the requirements of Paragraph 6(10)(e), Monitoring Instrumentation include:

Name of instrument installation subcontractors.

Layout of instrumentation points.

Procedures, forms and schedules for periodic submittals of readings.

(e) Settlement Survey Plan, to meet requirements of Paragraph 9(10)(f), Settlement Surveying. This plan may be submitted as part of the Instrumentation Monitoring Plan.

(4) Geotechnical and Environmental Investigation. Include the results of geotechnical and environmental investigations performed by the Contractor as relevant to tunneling in the Tunneling Work Plan.

5. Job Conditions.

(1) Design Criteria.

(a) Design the primary liner for appropriate loading conditions, including but not limited to: overburden and lateral earth pressures, handling and installation stresses, loads imposed by tunnel boring machine thrust jacks, subsurface soil and water loads, grouting, and all other conditions of service. Design the primary liner to carry the thrust of jacking or other construction forces or loads anticipated.

(b) Use HS-25 vehicle loading distributions for truck loading criteria in accordance with AASHTO.

(2) Safety Requirements:

(a) Perform work in a manner to maximize safety and avoid exposure of men and equipment to hazardous and potentially hazardous conditions, in accordance with applicable safety standards and the Contractor's safety procedures.

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

(c) Perform tunnel construction in manner that minimizes movement of ground in front and surrounding tunnel. Prevent significant subsidence of surface and protect structures and utilities above, and in the vicinity of, the tunnel from damage.

(d) Support the ground continuously in a manner to prevent the loss of ground and keep perimeters and faces of the tunnel and bottoms of shafts stable. Use filter-fabric and other means as necessary behind the primary liner to prevent soil migration into the tunnel.
(3) Air Quality:
   (a) Conduct tunneling operations by methods and with equipment which will
       positively control dust, fumes, vapors, gases or other atmospheric impurities in
       accordance with OSHA, Federal, State and City requirements.
   (b) Provide approved mining instrumentation for testing the quality of the tunnel
       atmosphere and obtain samples, under working conditions, at prescribed intervals
       in accordance with the above referenced requirements.

(4) Ground Conditions: As defined in Contract Documents.


(1) Preparation

   (a) The Contractor shall be responsible for 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 the 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.

   (c) Maintain clean working conditions inside the 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 the 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 the 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 or disruptions within the limits of the tunnel
       area unless otherwise approved by the Engineer.

(2) Ground Water Control and Ground Stabilization

   (a) Provide necessary ground water control measures to perform work and to provide
       safe working conditions. Prevent excessive inflow of water into excavations during
       construction of tunnel and installation of carrier pipe and grouting of annular space.
       The ground water control method shall provide a means to prevent piping of fines
       into shafts or tunnel and other adverse effects due to ground water inflow.

   (b) Anticipate that the tunnel excavation will be below the ground water table and in
       cohesionless soils. Install filter fabrics, backer-rods and other means as necessary
       to prevent piping of fines into tunnel. Remove water that may be encountered
       during the course of work by deep well pumping, or other means as necessary to
achieve stable conditions. Standing water will not be permitted at face, in tunnel or shafts.

(c) The ground water control method used shall not cause damage to adjacent structures or property due to lowering of the water table and subsequent ground settlement.

(d) If the Contractor chooses pumping installations to control ground water level or installs pervious liner through water bearing layers, install and maintain an instrumentation system to monitor the 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 the Engineer. Provide access to piezometers for the Engineer to perform independent measurements.

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

(f) 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 the ground water control operation or subsurface drainage into shafts or through a 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.

(g) Draw piezometric level down below the elevation of the invert of the tunnel, or to a lower elevation as required for excavation face and tunnel stability.

(3) Equipment

(a) Use a machine tunneling method with full-face closure capabilities.

(b) Diesel, electrical, hydraulic, or air-powered equipment will be acceptable, 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 the Contractor's operations from a source outside tunnel.

(c) Tunnel Boring Machine: Employ equipment that will be capable of handling various anticipated ground conditions. In addition, the TBM shall:

Be capable of minimizing loss of ground ahead of and around the machine and providing satisfactory support of the excavated face. Use a TBM with, when necessary for ground control, earth-pressure balance or slurry-shield capabilities.
Conform to the shape of the tunnel with a uniform perimeter that is free of projections that could produce over-excavation or voids. The TBM shield shall be continuous around its full perimeter; open-bottom shield is not acceptable.

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

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

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

Have motors and operating controls protected against water inflow.

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

Provide a means for maintaining the 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 the Engineer.

(d) Air Quality: Provide equipment to adequately ventilate the entire tunnel operation during construction.

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 the Contractor's safety plan.

Provide toxic and explosive gas detection equipment and an audible automatic gas alarm on the TBM to detect and warn of explosive and toxic gases. Locate the alarm near the tunnel face.

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

(e) Lighting: Provide adequate lighting with lights at a 50-ft., maximum spacing in the tunnel. Fixtures shall be in watertight enclosures with suitable guards. Provide separate circuits for lighting and for electrical equipment.

(f) Electrical: Equip electrical systems utilized on the TBM with an appropriate ground fault system. The electrical systems are to be insulated, not permitting bare-wire exposures.
(g) Access: Provide safe access through tunnel to the TBM.

Provide walkway in tunnels greater than 10 ft. in diameter that is separate from tracks used by spoil removal equipment.

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

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

(4) Shafts

(a) Shaft design must include allowance for Contractor’s equipment and stored material and spoil stockpile as appropriate.

(b) Construction of Shafts

Select shaft locations in agreement with the planned method of tunneling.

Appropriately size shafts.

Install liner elements, bracing and shoring structural members at locations and in method sequence and tolerances defined on shaft construction drawings as excavation progresses.

Ensure that the bracing and shoring are in contact with the liner to provide full support as shown in the shaft construction drawings. Install seal slab as soon as the final depth and stable bottom conditions have been reached and accepted by the Engineer. Construct a seal slab capable of withstanding full piezometric pressure, either by pressure relief using under drains, or in case of more permeable ground conditions, by use of a structural reinforced slab. Construct the seal slab in accordance with the design provided by the Contractor’s Professional Engineer.

Design and construct the entire shaft to the appropriate factors of safety against yield, deformation, or instability as determined by the Contract’s Professional Engineer. The shaft must withstand full hydrostatic head without failure.

Special framing, bracing or shoring required around the tunnel eyes” or other penetrations shall be in place according to the shaft construction drawings before the liner or any bracing or shoring at the penetration is cut or removed.

Securely breast and shore the face of starter or back tunnels to resist both soil and hydrostatic pressure.

When applicable, pressure gout voids or seepage paths around shafts and adjoining tunnels in accordance with grouting procedures in this Specification. Perform secondary or “back grouting” as ground measurement, voids or deformation of the shaft liner are detected.
If trench box is used in tunnel shaft and such utilization is in a manner other than what is indicated and certified in manufacturer’s technical data, submit trench box manufacturer certification of proposed usage.

(c) Install suitable thrust or reaction blocks as required for pipe jacking equipment.

(d) Provide drainage from shafts while work is in progress and until the adjacent pipe joints have been sealed and the shaft is backfilled.

(e) Surface Water Control: Divert surface water runoff and discharge from dewatering system away from shaft. Protect shafts from infiltration or flooding.

(f) Backfilling of Shafts

Backfill shall be in accordance to Item 400, “Excavation and Backfill for Structures.”

Remove shaft liner above level of 8 ft. below the ground surface, unless otherwise approved by the Engineer. Maintain sufficient ground support to meet excavation safety requirements while removing the shaft structure.

(5) Tunnel Excavation and Primary Liner Installation

(a) Tunnel Excavation:

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

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

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

During closed-face excavation:

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

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

(b) Size of Tunnel: Dimension as shown on the plans represent minimum dimensions acceptable to the Engineer and do not necessarily represent size or section suitable for the operational procedures as may be proposed or conducted by the Contractor. Construct 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.

(6) Primary Liner
(a) Provide primary liner for the tunnel that 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 the primary liner without significant settlement or movement of surrounding soil. To fill the void behind the primary liner, grout should be placed behind the liner. Grout excavation not to true shape as result of over excavation or loss of ground.

(c) The primary liner's seepage inflow for each 100-ft. length of tunnel shall not exceed 3 gallons per minute, including inflow through the 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 a means to prevent inflow of soil fines associated with water inflow by use of filter fabrics or other approved methods.

(7) Jacking of Casing

(a) Provide heavy-duty jacks of capacity suitable for forcing casing pipe through the 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 the casing pipe by use of excavating machine 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 a manner so that at least one third of the circumference of the excavation conforms to the contour and grade of the casing pipe. Provide clearance of not more than 2 in. for upper half of casing pipe with clearance tapering off to zero at point where excavation conforms to the 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) The distance that the excavation extends beyond the end of the casing pipe shall not exceed 3 ft. Decrease this distance as directed by the Engineer, or due to the character of the material being excavated.

(e) The casing pipe, insofar as practical, jack from low or downstream end. Lateral or vertical variation in final position of casing pipe from line and grade, as established by the Engineer, will be permitted only to the extent of 1 in. in 10 ft., provided that variation is regular and only in one direction and that the final grade of the flow line is in the direction indicated on plans. Remedy overcutting by pressure grouting the entire length of the installation. Use of grout mix immediately behind shield tail shall have efficient tail seal to prevent the flow of grout into the shield.
Depending on the character of soil encountered during the jacking operation, carry on the operation without interruption, insofar as practical, to prevent the casing pipe from becoming firmly set in the ground.

Remove and replace the casing pipe damaged in jacking operations at no additional cost to the State.

Backfill pits or trenches that have been excavated to aid jacking operations as soon as the 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 the shafts remain open without appropriate safety barricades, concrete traffic barriers (CTB's), railing or plates.

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

Grouting

(a) Furnish and operate suitable equipment for grouting operations to effectively and completely fill voids outside of the primary tunnel liner immediately after the tunnel liner installation is complete.

(b) Grout production and quality shall be in accordance with Contractor's mix design and grout production plan.

(c) Use care in grouting operations to prevent damage to adjacent utilities or other properties. Ensure that the pressure used in grouting is not great enough to distort or imperil work.

(d) Fill voids behind the primary liner with sand-cement grout promptly after liner is completely installed. Grout pressure shall not exceed value that may cause damage or distortion to tunnel liner. Grout from bottom up and plug each grout hole promptly after grout has been placed.

(e) Upon completion of grouting operation, sound primary liner and immediately correct voids discovered by necessary means as approved by the Engineer. After all voids are successfully filled, the grout holes will be packed, when necessary, with dry mortar mix and threaded taps securely placed in the holes.

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

(g) Perform quality control sampling and testing of grout.

Grout production shall be in accordance with the grout production plan.
Measure the density of the grout throughout the placement procedure as directed by the Engineer. Measure the grout density at the discharge point and discharge grout until density is within 0.3 pounds per gallon of the input density.

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

(9) Tunneling Data

(a) Submit shift logs of construction events and observations within 24 hours of operation on at least the following:

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

Observation of lost ground and other signs of ground movement.

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

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

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

Operation of shutdown periods or other interruptions in work, and reason.

Any unusual condition or event.

(b) Clearly mark the primary liner every 20 ft. along the tunnel with a distance in feet from the centerline of the preceding shaft.

(10) Control of Tunnel Line and Grade

(a) Construction Control

Check the established baseline and benchmarks indicated on the Drawings at the beginning of work and report any errors or discrepancies to the Engineer.

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

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

Establish control points sufficiently removed from the tunnel operation so as not to be affected by potential ground movement.
Maintain daily surveying records of the alignment and grade and submit three copies of records to the Engineer by the end of the day after work is performed. Locate points at the top, bottom and each side of the springline.

Check the tunnel survey control against above ground undisturbed reference at least once each day and once for each 50 ft. of tunnel constructed, or more often as needed or directed by the Engineer.

(b) Earth Movement

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

Refer to Paragraph 6(10)(e), Monitoring for detecting earth movement.

In event ground movement is detected, the Engineer may order that work be stopped and secured. Before proceeding, correct any problems causing or resulting from ground movement.

Be aware that when settlement of the ground surface should occur during construction of the tunnel which will affect the accuracy of temporary benchmarks established by the Engineer, detect and report movement. Advise the Engineer of any settlement affecting permanent monumentation benchmarks. Upon completion, submit field books pertaining to the monitoring of permanent monumentation benchmarks to the Engineer.

(c) Tunnel Line and Grade

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

When the excavation is off line and grade, make corrections to plan line and grade at the rate of 3 in. per 100 ft.

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

Alignment adjustments between primary tunnel liner and water main shall not encroach on minimum required clearance of 4 in.

If unable to maintain the specified tolerances, bear full responsibility and expense of correction (redesign, easement acquisition, etc.). When these tolerances are exceeded and the redesign of structures is required, obtain services of a qualified Professional Engineer registered in the State of Texas for the redesign. Submit plans showing changes to the Engineer for review.
Backfill (grout) and reconstruct the tunnel built outside the tolerance or which is outside State's right-of-way to be within the tolerance when so directed by the Engineer.

(d) Tunnel Connections, Terminations, and Temporary Bulkheads

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

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

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

(e) Monitoring

Monitoring Instrumentation: This specification establishes minimum instrumentation requirements for tunneling. Additional instrumentation requirements for critical areas may be specified elsewhere in Specifications or on Drawings. The Contractor may install a more extensive system at the Contractor's sole expense. The instrumentation specified shall be accessible at all times to the Engineer.

Install and maintain a system of instrumentation to monitor the 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.

Installation of instrumentation shall not preclude the Engineer, through an independent contractor or consultant, from installing instrumentation in, on, near, or adjacent to construction work. Provide access to work for independent installations.

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

Install extensometers to a depth of 5 ft. above crown of primary tunnel lining as shown on the Drawings to measure vertical movements in soils during and subsequent to tunneling. Extensometer consists typically of three-prong anchor, 1/4-in. standard stainless steel inner pipe, and 1-in. standard Schedule 80 PVC outer pipe. Pipes are assembled in sections and fastened together with standard couplings to required anchor depths. Locate the top of the extensometer within flush-mounted hand hole cover capable of withstanding HS-20 truck loading. Geotechnical instrumentation installation subcontractor shall provide procedures for the installation of extensometers as part of the Monitoring Plan.
Settlement Surveying: This specification establishes the minimum settlement survey requirements for structures and ground surface monitoring points.

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

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

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

Unless otherwise specified, record ground surface elevations on center line ahead of the TBM and at 20 ft. either side of center line at minimum of 100-ft. intervals or at least 3 locations per tunnel drive. Starting 100 ft. ahead of the TBM and continuing until the TBM is 100 ft. beyond the measurement point or until further movement is not detected, unless otherwise directed by the Engineer. Record cross-sectional points at 10-ft. spacing for distance of 50 ft. each side of the centerline or to the right-of-way, whichever is less.

Locate survey points at crossings under installations as follows:

- Roads: Centerline and each shoulder.
- Railroad: Track subbase at centerline of each track.
- Utilities and Pipelines: Directly above and 10 ft. before and after intersection.

Measure and maintain records of deformation of primary liner.

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

Immediately report to the Engineer any movement, cracking, or settlement which is detected and take immediate remedial action.

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

Disposal of Excess Material

Remove spoil from job site and dispose in lawful manner.
7. **Measurement.** Tunnel Casing will be measured by the linear foot installed. The casing will be measured along the axis of the casing.

8. **Payment.** The work performed and materials furnished by this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Tunnel Casing" of the size specified. This price shall be full compensation for all labor, materials, furnishing equipment, miscellaneous and incidentals necessary to complete the work described on the plans and specified herein, including tunnel excavation, liner, grouting, and instrumentation.

Excavation, backfill, backfill material and disposal of unsuitable excavated material for tunneling pits will not be paid for directly but will be considered subsidiary to these bid items.