

SECTION 31 72 13 – TUNNEL SUPPORT

PART 1 - GENERAL

1.1 DESCRIPTION

- A. This section specifies the minimum requirements for furnishing and installing the tunnel lining using shotcrete and rock dowels.

1.2 INFORMATIONAL SUBMITTALS

- A. Submit to the Engineer the following a minimum of 14 days before the scheduled start of the applicable activity:
 - 1. Tunnel Support Work Plan. Submit a detailed work plan of all proposed tunnel support operations. Include a description of proposed methods and procedures for scaling, cleaning, doweling, and installing welded wire mesh.
 - 2. Mix Design. A shotcrete mix design meeting the requirements herein. Shotcrete Application Work Plan. The shotcrete application work plan shall indicate dry-mix process or wet-mix process and shall include drawings and notes describing equipment, procedures and sequences for shotcrete production, application, curing, and applicable manufacturer's literature and recommendations. Include written documentation that verifies the qualifications of the nozzlemen that will be performing the work.
 - 3. Quality Control (QC) Plan. The QC plan shall address the following:
 - a. Procedures for meeting the minimum QC requirements described herein.
 - b. Procedures for any additional QC items.
 - c. Shotcrete curing method.
 - d. Cold weather placement and curing procedures.

1.3 QUALITY CONTROL

- A. Perform shotcrete work in accordance with the requirements of ACI 506.2 except as modified herein.
- B. Qualifications:
 - 1. Shotcrete Supervisor. The Contractor shall provide a Supervisor responsible for proper shotcrete application. The Supervisor shall have at least five years' experience in the placement of overhead shotcrete.
 - 2. Nozzlemen:
 - a. Each nozzleman shall have had at least one year of experience in the application of overhead shotcrete. Each nozzleman shall be certified in accordance with ACI CP-60. Each nozzleman shall demonstrate, to the satisfaction of the Engineer, acceptable proficiency in the application of shotcrete to overhead test panels before beginning production work.

- C. Laboratory and Field Testing:
1. Perform field index testing to determine slump, density, air content, and temperature. Index testing shall be performed by an independent materials testing laboratory, contacted and paid for by the Contractor.
 2. The Contractor shall make field trials of overhead shotcrete panels using the proposed shotcrete mix to demonstrate the capability of the equipment, workmanship, and materials under field conditions prior to actual application of shotcrete in the work.
 3. Field application of shotcrete for the field trial shall comply with the requirements of ACI 506.2 and as specified. Make a 24" x 24" x 6-in. thick test panel for each mix being considered in compliance with the applicable provisions of ASTM C 1140. Test placements shall be made by each nozzleman proposed to perform shotcrete work.
 4. Cure test panels in accordance with ASTM C 31. Take a minimum of five 3-in. diameter core specimens from panels for testing. The specimens shall be obtained, prepared and tested in accordance with ASTM C 42. The average compressive strength of three cores taken from test panels must equal or exceed 85 percent of the specified compressive strength.
 5. All phases of field trial work shall be performed in the presence of the Engineer.
 6. Field index testing and test panels shall be performed for every 50 cubic yards of shotcrete produced.
 - a. The compressive strength of shotcrete shall meet the following minimum compressive strength requirements:
 - 1) 2,000 psi at 72 hours
 - 2) 3,000 psi at 7 days
 7. All costs for developing shotcrete mixes including field trials and laboratory tests shall be at the expense of the Contractor and shall be considered incidental work under this Section.
 8. The Engineer will have the right to require the Contractor to perform additional test panels and/or core production shotcrete when shotcrete strengths and quality are in question.

PART 2 - PRODUCTS

2.1 MATERIALS

- A. Rock Dowels:
1. Rock dowels shall conform to ASTM A 615 Grade 75 thread bars. The rock dowels end hardware shall be as recommended by the rock dowel manufacturer.
 2. Bearing plates shall conform to ASTM 36.
 3. Resin grout shall conform to rock dowel manufacturer specifications. Use one brand of resin throughout the project.
- B. Shotcrete:
1. Cement shall conform to ASTM C 150. Use one brand of cement throughout the project.
 2. Silica fume, if used, shall comply with ASTM C 1240.
 3. Fly ash, if used, shall conform to the requirements of ASTM C618, Type F

4. Aggregate: Use normal weight aggregates conforming to the requirements of ASTM C33. Aggregate shall be uniformly well graded and shall not exhibit extremes of variation in accordance with ASTM C 33.
5. The gradation of the combined coarse and fine aggregate mixture shall conform to the following limits:

Percent Passing (By Weight)	
U.S. Standard Sieve Size	Gradation
1/2 inch	100
No. 4	70-85
No. 100	2-10
No. 200	<2

6. Water shall be potable.
 7. Admixtures shall conform to the requirements of ASTM C 1141. Air-entraining admixtures shall conform to the requirements of ASTM C260.
 8. Admixtures shall not contain the following:
 - a. Chlorides;
 - b. Materials that may cause other detrimental effects such as cracking or spalling;
 - c. Materials corrosive to steel.
 9. Hydration control admixtures shall not cause a decrease in concrete strength with age.
- C. Strip Drains shall be 12" wide with a drainage core and geotextile encapsulation at least on the rock side. Each strip drain shall have a minimum flow rate of 0.1 gallons per second under a gradient of 1.
- D. Welded Wire Fabric. Welded wire fabric shall conform to ASTM A 185.

2.2 SHOTCRETE MIX

- A. Shotcrete proportioning and placement shall comply with the requirements of ACI 506.2, "Specifications for Materials, Proportioning and Application of Shotcrete," and the requirements of Section 601 (Class Shotcrete), except as herein modified.
- B. Provide a mix that is plastic enough to give good compaction and low percentage of rebound, but stiff enough not to sag. Silica fume, rheology control agents, and/or fly ash shall be used to achieve these properties. The maximum water:cementitious materials ratio by weight shall be 0.40. Accelerator, if used, shall be applied by a dosage pump synchronized with the shotcrete pump so that accelerator is not applied directly to freshly installed shotcrete surfaces and that the accelerator dosage is the minimum necessary to achieve the desired set time.
- C. The minimum air content of the shotcrete mix shall be 10% at the pump.
- D. Slump at the pump shall be between 1 and 3 in. when measured in accordance with ASTM C143.
- E. The shotcrete temperature at the pump shall be between 50°F and 90°F at the pump.

2.3 EQUIPMENT

- A. **Mixing Equipment:** Capable of thoroughly mixing aggregate, cement, and water in sufficient quantity to maintain continuous placement.

Placing Equipment: Capable of discharging aggregate-cement-water mixture accurately, uniformly, and continuously through delivery hose. The Contractor shall select equipment with demonstrated capability to apply overhead shotcrete in the confined spaces and in the thicknesses required for this work.

PART 3 - EXECUTION

3.1 GENERAL

- A. Deliver, store and handle materials to prevent contamination, segregation, corrosion or damage. Store approved liquid admixtures in order to prevent evaporation and freezing.
- B. Maintain responsibility for the safety of the work and the protection of personnel performing the work. Furnish and install ancillary support as needed to meet this responsibility.
- C. Scaling and cleaning of the shotcrete surfaces shall occur prior to shotcreting operations. After scaling for loose rock, the rock surfaces shall be power washed to removed grime and loose dirt to provide an acceptable surface for the shotcrete to bond to.
- D. Verify that field conditions are acceptable and are ready to receive work and field measurements are as shown on the Contract drawings and shop drawings.
- E. Install rock dowels as shown on the plans.
- F. Install drip drains as shown on the plans.
- G. Secure welded wire mesh to the rock surface with the minimum offset shown on the plans.
- H. Shotcrete shall be applied at the locations and to the thicknesses shown on the plans. The thickness of shotcrete shall not be less than the dimensions shown on the plans. Initial shotcrete placement to fill large existing voids may be performed prior to placing the welded wire mesh.

3.2 INSTALLATION OF TUNNEL SUPPORT

- A. **Rock Dowels**
 - 1. **General:**
 - a. Drill each hole at the diameter recommended by the manufacturer, and length as shown on the plans.
 - b. Drill holes normal to the theoretical excavation surface unless otherwise required to support specific rock blocks.

- c. All drill holes shall be cleaned of all loose material and dust down to the bottom of the hole.
 2. Resin-Grouted Rock Dowels:
 - a. Use the appropriate number and type of resin cartridges, considering set times, prevailing temperatures, hole diameter and length, and bar diameter and length as specified by the manufacturer.
 - b. If resin does not encapsulate the rock dowel to within 18-in. of the face of the hole after inserting the bar and spinning, remove and discard the rock dowel and install a replacement within 12 in. of the unsatisfactorily installation.
 - c. If resin encapsulates the rock dowel to within 18-in. of the face of the hole after inserting the bar and spinning, the remainder of the rock dowel shall be grouted to the face of the hole, as required. Perform this grouting within seven days of installation using epoxy or cement grout.
- B. Shotcrete
 1. Preparation:
 - a. Installation of strip drains and welded wire mesh. Overlap welded wire mesh panels by two grids minimum.
 - b. Rock surfaces, which are to receive shotcrete, shall be scaled and cleaned of all loose material, mud and other foreign matter by means of water jet.
 - c. Groundwater Control:
 - 1) Contractor shall perform groundwater control, drainage, and diversion that is acceptable to the Engineer to remove flowing water from the liner surfaces, prior to the application of shotcrete in each area to receive shotcrete.
 - 2) Drill drain and weep holes through shotcrete as indicated to ensure that hydrostatic pressure does not develop. Install drain pipes as indicated and allow pipes to drain freely after shotcrete installation.
 2. Placement: Place in accordance with ACI 506R
 3. Cold weather shotcreting: The rock on which shotcrete is to be placed shall not have visible ice, frost, or snow on the surface. The minimum shotcrete temperature at the pump shall be 50 deg. F. This may be achieved by the use of hot water. When the minimum of the ambient and out-of-nozzle air temperature during application is less than 35 deg. F, one test panel shall be prepared from each shotcrete batch. The test panel shall be field cured under the same curing conditions as the shotcrete placed on the tunnel from the same batch and at least one core from the test panel shall be tested for unconfined compressive strength at 28 days.

The temperature of placed shotcrete shall be maintained above 50 deg. F until that shotcrete has achieved an unconfined compressive strength of at least 750 psi. Protection measures during this initial curing period may consist of blankets, tenting, or heaters. If heaters are used, exhaust gasses shall be vented outside the shotcrete blankets and tenting to prevent carbonation from CO₂ exposure and the temperature of the shotcrete surface shall be carefully monitored to prevent excessive drying.

Note that this minimum strength requirements is only to prevent freeze damage to the shotcrete. The minimum strength requirement prior to placing additional shotcrete may be greater. After the initial curing period, limit rapid temperature changes in the shotcrete when the protection is removed. The shotcrete temperature shall not be allowed to more than 50 deg. F in the first 24 hours and blankets and tents shall not be

completely removed unless the temperature of the shotcrete is within 50 deg. F of the ambient air temperature. These requirements may result in the extended use of protection measures. Recording thermometers should be placed under the blankets at different locations along the length of the tunnel. These thermometers should be checked to identify any possible issues with the winter protection system and adjustments made to the plan as necessary.

4. Curing: Cure shotcrete in accordance with ACI 506.2

3.3 ACCEPTANCE

- A. Acceptable shotcrete shall consist of a dense uniform concrete, without major rebound inclusions, and without discernible weakness of bond between layers or other defects as described herein.
- B. After shotcrete set-up, all shotcrete areas shall be sounded. Acceptable shotcrete will show no signs of sand pockets or hollow areas.
- C. Acceptable shotcrete will show no signs of sagging.
- D. Acceptable shotcrete will show no signs of honeycombing.
- E. Acceptable shotcrete will show no signs of material segregation.
- F. The Engineer reserves the right to order removal of defective shotcrete and its replacement with acceptable shotcrete without additional cost to the Owner. Any portion of the shotcrete that is unsatisfactory shall be cut out and replaced with new shotcrete. Any repair of unsatisfactory shotcrete shall be done at the Contractor's expense.
- G. The Engineer reserves the right to disqualify the nozzleman if the nozzleman cannot produce acceptable shotcrete.

3.4 REPAIR OF DEFECTS

- A. Defective areas, as determined by the Engineer, shall be removed and replaced with fresh shotcrete. Defects include, but are not limited to, honeycombing, lamination, dry patches, voids, or sand pockets.
- B. All repairs shall be made within a time period as accepted by the Engineer.

END OF SECTION 31 72 13