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USACE / NAVFAC / AFCEA

UFGS-02430 (August 2004)

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Preparing Activity: USACE (CW)

Superseding

UFGS-02430A (July 1995)

## UNIFIED FACILITIES GUIDE SPECIFICATIONS

References are in agreement with UMRL dated 22 December 2004

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### SECTION 02430

#### TUNNEL AND SHAFT GROUTING 08/04

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NOTE: This guide specification covers the requirements for furnishing all plant, labor, equipment, and materials and performing all operations in connection with tunnel and shaft grouting applicable to constructing new and repairing existing underground structures.

Comments and suggestions on this guide specification are welcome and should be directed to the technical proponent of the specification. A listing of technical proponents, including their organization designation and telephone number, is on the Internet.

Recommended changes to a UFGS should be submitted as a Criteria Change Request (CCR).

Use of electronic communication is encouraged.

Brackets are used in the text to indicate designer choices or locations where text must be supplied by the designer.

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## PART 1 GENERAL

### 1.1 REFERENCES

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NOTE: Issue (date) of references included in project specifications need not be more current than provided by the latest guide specification. Use of SpecsIntact automated reference checking is recommended for projects based on older guide specifications.

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The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

ASME INTERNATIONAL (ASME)

ASME B16.3	(1998) Malleable Iron Threaded Fittings
ASME B16.5	(2003) Pipe Flanges and Flanged Fittings
ASME B16.9	(2003) Factory-Made Wrought Steel Buttwelding Fittings

ASTM INTERNATIONAL (ASTM)

ASTM A 53/A 53M	(2004a) Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless
ASTM C 117	(2004) Materials Finer Than 75 micrometer (No. 200) Sieve in Mineral Aggregates by Washing
ASTM C 136	(2004) Sieve Analysis of Fine and Coarse Aggregates
ASTM C 150	(2004a) Portland Cement
ASTM C 494	(1992) Chemical Admixtures for Concrete
ASTM C 618	(2003) Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete
ASTM C 937	(2002) Grout Fluidifier for Preplaced-Aggregate Concrete
ASTM C 939	(2002) Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method)
ASTM C 940	(1998a; R 2003) Expansion and Bleeding of Freshly Mixed Grouts for Preplaced-Aggregate Concrete in the Laboratory
ASTM C 942	(1999) Compressive Strength of Grouts for Preplaced-Aggregate Concrete in the Laboratory

U.S. ARMY CORPS OF ENGINEERS (USACE)

COE CRD-C 400	(1963) Requirements for Water for Use in Mixing or Curing Concrete
EM 1110-1-3500	(1995) Chemical Grouting
EM 1110-2-2901	(1997) Tunnels and Shafts in Rock
EM 1110-2-3506	(1984) Grouting Technology
EM 385-1-1	(2003) Safety -- Safety and Health Requirements

## 1.2 UNIT PRICES

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NOTE: If Section 01025 MEASUREMENT AND PAYMENT is included in the project specifications, this paragraph title (UNIT PRICES) should be deleted from this section and the remaining appropriately edited subparagraphs below should be inserted into Section 01025.  
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### 1.2.1 Mobilization and Demobilization

#### 1.2.1.1 Payment

Payment will be made for costs of assembling all plant and equipment at the site preparatory to initiating the work and for removing it when the drilling and grouting has been completed. Sixty (60) percent of the contract lump-sum price for mobilization and demobilization will be paid following completion of moving onto the site, including complete assembly, in working order, of all equipment necessary to perform the required drilling and grouting operations. The remaining forty (40) percent of the contract lump-sum price will be paid when all equipment has been removed from the site.

#### 1.2.1.2 Unit of Measure

Unit of measure: lump sum.

### 1.2.2 Drilling Grout Holes

#### 1.2.2.1 Payment

Payment will be made for costs associated with drilling and redrilling grout holes; washing and pressure testing of grout holes; containing and disposing of waste water and waste grout; clean-up of the site; furnishing, handling, transporting and storing of grout materials; and for furnishing all labor and supplies incidental to the work. [Unless otherwise specified, no] [No] separate payment will be made for any material constituent of the grout, including cement and/or chemical grout materials placed in the performance of contract grouting. No payment will be made for grout, or the material constituents thereof, wasted due to improper anchorage of grout pipe or connections, or which is wasted due to negligence on the part of the Contractor, nor for grout which is rejected by the Contracting Officer because of improper mixing. Payment will be made at the applicable contract unit prices for materials contained in grout which are wasted, where the wasting is not due to negligence on the part of the Contractor.

#### 1.2.2.2 Measurement

Drilling of grout holes will be measured for payment on the basis of the linear meters feet of holes actually drilled in concrete, rock or soil, as shown or as directed, including all intermediate holes at locations where pipe was not installed.

#### 1.2.2.3 Unit of Measure

Unit of measure: linear meter foot.

### 1.2.3 Drilling Drain Holes

#### 1.2.3.1 Payment

Payment will be made for costs associated with drilling of drain holes actually drilled in concrete, rock, or soil, as shown or as directed.

#### 1.2.3.2 Measurement

Drilling of drain holes will be measured for payment on the basis of the linear meters feet of holes actually drilled in concrete, rock, or soil, as shown or as directed.

#### 1.2.3.3 Unit of Measure

Unit of measure: linear meter foot.

### 1.2.4 Drilling Exploratory Holes

#### 1.2.4.1 Payment

Payment will be made for costs associated with drilling of exploratory holes.[ Core boxes shall be provided at no additional cost to the Government.]

#### 1.2.4.2 Measurement

Drilling of exploratory holes will be measured for payment on the basis of the linear meters feet of holes actually drilled in concrete, rock, or soil, as directed by the Contracting Officer.

#### 1.2.4.3 Unit of Measure

Unit of measure: linear meter foot.

### 1.2.5 Placing Grout

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**NOTES: Select appropriate alternatives.**

**Under certain conditions it may be desirable to include a pay item for standby time for Government directed suspension of drilling or grouting operations.**

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#### 1.2.5.1 Payment

[Payment will be made for costs associated with satisfactorily placing grout in contact grout holes[ and behind steel liner], which includes full compensation for[ furnishing all materials,] proportioning the mix as directed,[ drilling grout holes if necessary,] and mixing and injecting the grout as specified or as directed.][Payment will be made for costs associated with satisfactorily placing grout in grout holes, which includes full compensation for proportioning the mix, mixing, and injecting the grout as specified or as directed. Separate payment will be made for all materials used in [contact ]grout as provided in unit price pay item(s) "Portland Cement in Grout" "Mineral Filler in Grout", "Sand in Grout",

"Fluidifier in Grout", and "Chemicals in Chemical Grout".]

#### 1.2.5.2 Measurement

[The operation of placing grout will be measured for payment on the basis of the number of cubic meters cubic feet of the component materials (bulk materials), satisfactorily placed, exclusive of water [and fluidifier] and regardless of the proportions of the mixes, measured individually as specified in unit price pay items "Portland Cement in Grout", "Mineral Filler in Grout", and "Sand in Grout".]

[The operation of placing grout will be measured for payment on the basis of the number of hours of satisfactory placing regardless of the proportions of the mixes. Measurement will begin with the initiation of grout injection at the proper elevation or stage and continue until grout injection ceases, for a given hole, exclusive downtime. Downtime is defined as any failure to inject grout continuously, except for intermittent grouting as directed by the Contracting Officer. Time will be measured cumulatively to the next whole hour of operation. Payment for placing grout in holes will be based on the total amount of time required for satisfactorily placing grout, determined by reducing the total number of minutes of operation to the nearest whole hour.]

#### 1.2.5.3 Unit of Measure

Unit of measure: [cubic meter foot][nearest whole hour].

#### 1.2.6 Connections to Grout Holes

##### 1.2.6.1 Payment

\*\*\*\*\*  
**NOTE: The price to be inserted in this paragraph**

**should be determined on the basis of the estimated cost to the Contractor for the operation of moving the grout supply line onto the hole. This price should not include any allowance for pipe or other materials used in making the connections. This unit price pay item may be optional for grout payment on an hourly basis.**

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[Payment will be made for costs associated with connections to grout holes at a rate of [\_\_\_\_\_] dollars per connection.] [Payment for only one connection will be made for each hole regardless of the number of settings.]

##### 1.2.6.2 Measurement

Connections to grout holes will be measured for payment per connection for each time the grout supply line is connected to the ring grout hole or an exploratory hole for the purpose of injecting grout, regardless of the number of times such connections are made per hole or the amount of grout actually injected.

##### 1.2.6.3 Unit of Measure

Unit of measure: each.



#### 1.2.7 Portland Cement in Grout

##### 1.2.7.1 Payment

Payment will be made for costs associated with Portland cement in grout.

##### 1.2.7.2 Measurement

Portland cement in grout will be measured for payment on the basis of the number of cubic meters (42.6 kg) cubic feet (94 pounds) of cement used in the grout satisfactorily placed in ring grout holes and in filling exploratory holes, or wasted when such wasting is not due to the Contractor's negligence.

##### 1.2.7.3 Unit of Measure

Unit of measure: meter (42.6 kg) cubic foot (94 pounds).

#### 1.2.8 Mineral Filler in Grout

##### 1.2.8.1 Payment

Payment will be made for costs associated with mineral filler in grout.

##### 1.2.8.2 Measurement

Mineral filler in grout will be measured for payment on the basis of the number of cubic meters (36.3 kg) cubic feet (80 pounds) of filler used in the grout and satisfactorily placed in grout holes.

##### 1.2.8.3 Unit of Measure

Unit of measure: cubic meter (36.3 kg) cubic foot (80 pounds).

#### 1.2.9 Sand in Grout

##### 1.2.9.1 Payment

Payment will be made for costs associated with sand in grout.

##### 1.2.9.2 Measurement

Sand in grout will be measured for payment on the basis of the number of cubic meters cubic feet of sand [, dry rodded measurement,] used in the grout satisfactorily placed in ring grout holes or in filling exploratory holes.

##### 1.2.9.3 Unit of Measure

Unit of measure: cubic foot.

#### 1.2.10 Fluidifier in Grout

##### 1.2.10.1 Payment

Payment will be made for costs associated with fluidifier in grout [, including full allowance for the payment by the Contractor of all required royalties].

#### 1.2.10.2 Measurement

Fluidifier in grout will be measured for payment on the basis of the number of pounds of fluidifier used in the grout satisfactorily placed in ring grout holes.

#### 1.2.10.3 Unit of Measure

Unit of measure: kilogram pound.

#### 1.2.11 Chemicals in Chemical Grout

##### 1.2.11.1 Payment

Payment will be made for costs associated with chemicals in chemical grout.

##### 1.2.11.2 Measurement

Chemicals in chemical grout will be measured for payment on the basis of the number of gallons of chemicals actually used in grout mixtures satisfactorily placed in ring grout holes.

##### 1.2.11.3 Unit of Measure

Unit of measure: kilogram pound.

#### 1.2.12 Steel Pipe and Fittings

##### 1.2.12.1 Payment

Payment will be made for costs associated with embedded grout and drain hole pipe and fittings remaining in the permanent work, which includes costs for removal of pipe and fittings, and patching and cleanup pursuant to Section 02430 TUNNEL AND SHAFT GROUTING, paragraph PATCHING AND CLEANUP. All pipe and fittings removed shall become the property of the Contractor.

##### 1.2.12.2 Measurement

Embedded pipe and fittings through which holes will be drilled and grouted, as shown and as directed or approved, will be measured for payment on the basis of the actual [kilograms][linear meters] [pounds][linear feet][, as differentiated by pipe size and schedule number,] of satisfactorily installed pipe and fittings left in place. No additional allowance will be made for [overweight][differences] caused by installation of oversized pipe (diameter or length) and pipes that are not specified or approved. Upon completion of the grouting, no additional allowance will be made for costs of cutting off and removing from the project site all grout pipe connections protruding from the inside face of the concrete liner.

##### 1.2.12.3 Unit of Measure

Unit of measure: kilogram pound.

#### 1.2.13 Pressure Washing and Pressure Testing

##### 1.2.13.1 Payment

Payment will be made for pressure washing, and pressure testing of grout holes and pressure testing of exploratory holes, which includes the cost of

preliminary washing, materials for washing and testing, and making and breaking connections incidental to the work. Payment will be based upon the total amount of time required for pressure washing and pressure testing, determined by reducing the total number of minutes of operation to the nearest whole hour. No payment will be made for time lost due to fault or negligence of the Contractor, or due to defective equipment furnished by the Contractor.

#### 1.2.13.2 Measurement

Pressure washing and pressure testing will be measured for payment on the basis of the actual time water pumps are operating. Pressure washing and pressure testing will be measured from the time pumping is begun on a hole or section of a hole until the time pumping is completed on the hole or section of the hole as determined by the Contracting Officer. Time will be measured cumulatively to the next whole minute of operations.

#### 1.2.13.3 Unit of Measure

Unit of measure: nearest whole hour.

### 1.3 SYSTEM DESCRIPTION

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**NOTE: The work will be under the direction of the Contracting Officer or his authorized representative, i.e., Government Representative who will be an engineering geologist or geotechnical engineer experienced in the design and grouting of tunnels and shafts.**  
\*\*\*\*\*

This section describes the equipment, materials, and procedures to perform drilling and grouting work. It covers the equipment and materials to use; drilling grout, drain and exploratory holes; installing grouting pipe and fittings; connections to grout holes; furnishing, handling, transporting, storing, mixing, and injecting grout; handling, controlling, and disposing of drill cuttings, waste water, and waste grout; patching finished grout and exploratory holes; final cleanup upon completion of work and all other operations incidental to drilling and grouting. The work consists of drilling exploratory and drain holes as directed or shown and performing [contact] [ and ] [tunnel and shaft] [and ] [steel liner] [ and ] [ring curtain] grouting as shown. Exploratory drilling may be required to define problem areas or verify results ahead of the working face or through the lining during construction. The total amount of drilling and grouting required is not known and will be determined by conditions encountered as the work progresses. Grouting mixes, pressures, pumping rates, and the sequence in which holes are drilled and/or grouted will be determined in the field and shall be as directed. Work under this section shall be in accordance with EM 1110-1-3500, EM 1110-2-2901, and EM 1110-2-3506

### 1.4 SUBMITTALS

\*\*\*\*\*  
**NOTE: Submittals must be limited to those necessary for adequate quality control. The importance of an item in the project should be one of the primary factors in determining if a submittal for the item should be required.**

A "G" following a submittal item indicates that the submittal requires Government approval. Some submittals are already marked with a "G". Only delete an existing "G" if the submittal item is not complex and can be reviewed through the Contractor's Quality Control system. Only add a "G" if the submittal is sufficiently important or complex in context of the project.

For submittals requiring Government approval on Army projects, a code of up to three characters within the submittal tags may be used following the "G" designation to indicate the approving authority. Codes for Army projects using the Resident Management System (RMS) are: "AE" for Architect-Engineer; "DO" for District Office (Engineering Division or other organization in the District Office); "AO" for Area Office; "RO" for Resident Office; and "PO" for Project Office. Codes following the "G" typically are not used for Navy projects.

Submittal items not designated with a "G" are considered as being for information only for Army projects and for Contractor Quality Control approval for Navy projects.

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Government approval is required for submittals with a "G" designation; submittals not having a "G" designation are [for Contractor Quality Control approval.] [for information only. When used, a designation following the "G" designation identifies the office that will review the submittal for the Government.] The following shall be submitted in accordance with Section 01330 SUBMITTAL PROCEDURES:

#### SD-02 Shop Drawings

Drilling Operations  
Pressure Washing and Pressure Testing Operations  
Cement and Chemical Grouting Operations

Submit duplicate records of all grout hole and drain hole drilling operations, all pressure washing and pressure testing operations, and all cement and chemical grouting operations. The Government must receive the originals of all such records before final payment will be processed.

#### SD-03 Product Data

##### Qualifications

Submit evidence that the grouting specialist or grouting foreman has had at least 3 years experience within the past 5 years on similar grouting type projects.

Grouting Equipment[; G][; G, [\_\_\_\_]]

Submit a plan of the proposed grouting equipment types and

layout for approval.[ An example of a typical grouting equipment layout is included at the end of this section.]

Grout Application[; G][; G, [\_\_\_\_\_]]

Submit the method to be used in applying the grout.

#### SD-04 Samples

Grouting Material Samples[; G][; G, [\_\_\_\_\_]]

Submit samples of grouting material for Government testing and approval.

### 1.5 QUALIFICATIONS

Grouting shall be performed by a specialty contractor or subcontractor experienced and competent in [cement grouting] [chemical grouting] [both cement and chemical grouting]. All grouting work shall be done under the direct field supervision of a qualified grouting specialist or grouting foreman whose qualifications have been provided to the Contracting Officer.

The foreman or specialist shall supervise the performance of the work in compliance with these specifications.

### 1.6 CONSTRUCTION SEQUENCE

Grouting shall be done in the work sequence as shown and as specified. [[Contact grouting] [ and/or ] [grouting behind steel liner] shall be done at a reasonable time following installation of the permanent liner and prior to any application of internal or external water pressure, air shock, or vibration.][ Tunnel and shaft grouting or ring grouting shall be done at the appropriate time during the excavation/muck/support mining cycle to achieve the desired water flow reduction or stabilization prior to the passage of any water within the tunnel or shaft.] Grouting, once started, shall normally proceed to completion without significant interruption.

## PART 2 PRODUCTS

### 2.1 GROUTING MATERIALS

Grout shall be of a nonshrink type and normally composed of water, cement, and fluidifier with shrinkage compensators (expanding agents). Sand, admixtures to vary grout properties, and mineral fillers shall also be used as specified or approved. The grout mixes will be designed or approved by the Contracting Officer and will be varied to meet the characteristics of each hole or situation as determined by the conditions encountered. The various materials furnished shall conform to the following paragraphs.

#### 2.1.1 Water

[The water used in the grout shall be furnished by the Contractor. It shall be fresh, clean, and free of sewage, oil, or organic matter and injurious amounts of acid, alkali, and salts or other damaging substances as determined by COE CRD-C 400.] [Water suitable for use in the work will be furnished by the Government. The Contractor shall provide any necessary connections and extensions to the Government supply line.]

### 2.1.1.2 Cement

\*\*\*\*\*  
NOTE: Designer should insert the Section number and  
title that specifies the storage requirements for  
cement.  
\*\*\*\*\*

Cement used in grout shall conform to the requirements of ASTM C 150, Portland cement Type [\_\_\_\_]. Storage of cement shall be in accordance with Section [03\_\_\_\_] [\_\_\_\_]. The Contractor shall employ methods of handling, transporting, and storage that are satisfactory to the Contracting Officer. Only cement furnished in cloth or paper bags will be accepted for use in the work unless bulk cement is approved. A sufficient quantity of cement shall be stored at or near the site of the work to ensure that grouting operations will not be delayed due to shortage of cement. Care shall be taken in storage and handling to protect the cement from contamination and moisture. In the event the cement contains lumps or foreign matter that will not pass through a standard #100 mesh screen, the cement shall be removed from the work site and replaced at no cost to the Government.

### 2.1.1.3 Sand

Sand for grout shall consist of hard, tough, durable, uncoated particles. It may be composed of [natural sand] [manufactured sand] [a combination of natural and manufactured sand]. The shape of the particles shall be generally rounded or cubical and shall not contain more than 5 percent of flat or elongated pieces having a maximum dimension in excess of five times the minimum dimension. If the sand is a combination of separately processed sizes, classification, or a combination of natural and manufactured sands, the different components shall be batched separately, or, subject to written approval, blended prior to delivery to the mixing plant. The sand shall be well-graded from fine to coarse, and the gradation, as determined in accordance with ASTM C 136 and ASTM C 117, shall conform to the following requirements:

SIEVE DESIGNATION (U.S. STANDARD SQUARE MESH)	CUMULATIVE PERCENTAGE BY WEIGHT	
	PASSING	RETAINED
8	100	0
16	95-100	0-5
30	60-85	15-40
50	20-50	50-80
100	10-30	70-90
200	0-5	95-100

In addition to the grading limits shown, all sand used in the work shall have a fineness modulus within the range of 1.50 to 2.00. The grading of the sand as delivered to the mixes, during any 24-hour period of operation, shall be controlled so that the fineness moduli of samples taken will not vary more than 0.10 from the average fineness modulus. The results of previous tests and the service record may be used to determine the acceptability of the sand. Sand shall be stored in a manner to facilitate drainage and avoid the inclusion of any foreign materials in the grout. The storage piles shall be constructed to prevent segregation and contamination.

#### 2.1.4 Admixtures

An admixture is any material other than water, sand, and cement added to the grout immediately before or during its mixing to alter its chemical or physical properties to a desired characteristic during its fluid or plastic state. Admixtures shall conform to ASTM C 494 at the time of acceptance testing sample submittal, and the Contractor shall furnish certification from the manufacturer that the material meets all the requirements of these specifications. All admixtures to be used in each batch of grout shall be separately packaged and weighed prior to use. Grout fluidifier and expanding agents shall conform to the requirements of ASTM C 937. Accelerator additive shall be calcium chloride ( $\text{CaCl}_2$ ) in amounts up to 2 percent (2%) of the cement by weight or an approved product manufactured for the specific purpose of accelerating grout set-up time. The calcium chloride shall be granular or flaked and added to the grout by dissolving it in a portion of the mix water.

#### 2.1.5 Mineral Filler

Fillers used in grout as replacement for a portion of the cement shall be fly ash composed of finely divided siliceous residue and in accordance with ASTM C 618, Class F. The maximum amount of fly ash should not exceed 30 percent (30%) of the cement by weight.

#### 2.1.6 Chemical Grouting Materials

\*\*\*\*\*  
**NOTE: Designers should seek information from chemical grout suppliers and manufacturers and other reference material on the subject about which type(s) of chemical grout is best suited for their particular application and job.**  
\*\*\*\*\*

Grouting materials shall be nonflammable and the type used in grouts that are either water-based (gel forming) or water-reactive (foam forming). Only the following water-based chemical types shall be used; silicates, acrylates, polyacrylamides, acrylamides (only certain products), modified tannin, and epoxy resins. Only the following water-reactive chemical types shall be used; polyurethanes and elastomers. Chemical compounds shall be EPA approved. A sufficient quantity of chemical grouting materials shall be stored at or near the work site to ensure that grouting operations will not be delayed due to storage of these materials. Storage requirements, mixing, and handling of all component materials as well as the grout mixture itself shall be in accordance with the manufacturer's or supplier's recommendations.

### 2.2 GROUT

#### 2.2.1 Cement Grout

The grout mixture shall be designed to expand [3 to 5 percent] [2 to 4 percent] when tested in accordance with ASTM C 940. Grout flow time-of-efflux, when tested in accordance with ASTM C 939 shall be [between 10 and 30 seconds]. The unconfined compressive strength of the solidified grout shall range between [3.5 and 13.8] [13.8 and 20] MPa [500 and 2,000] [2,000 and 3,000] psi when tested in accordance with ASTM C 942.

### 2.2.2 Chemical Grout

Chemical grout shall be composed of commercially available materials consisting of base material, reactant, water, and accelerator if required. Set times for chemical grout shall be controllable from 1 to 30 minutes following injection. All components shall be compatible with each other and with the rock or soil and groundwater. The Contractor and manufacturer shall certify that the proposed grout is chemically stable and will not render surrounding groundwater unpotable. [ The grout mix shall be such that when injected in medium dense Ottawa 20-30 sand and tested by an approved method, the unconfined compressive strength of the grouted sand shall average at least 690 kPa 100 psi.]

### 2.2.3 Grouting Material Samples

\*\*\*\*\*  
**NOTE: The Designer should insert the name and address of the Division Laboratory where material samples are to shipped and tested.**  
\*\*\*\*\*

The Contractor shall ship grouting material samples for acceptance laboratory testing to:

[ ] Division Laboratory  
[ ]  
[ ]

The samples shall include:

- a. 5 sacks (or 213 kg 470 pounds) of cement
- b. 68 kg 150 pounds of mineral filler
- c. 2.25 kg 5 pounds of additive(s)
- d. 0.75 cubic meter 1 cubic yard of sand
- e. 4 L 1 gallon of chemical grout (to include reactant and catalyst)

Each sample shall be from the manufacturer or supplier and representative of the materials to be used in the work or from the shipment received at the work site. Shipment shall be made to permit arrival at the lab 28 calendar days before the earliest start of grouting. Any substitution of materials after mix design is approved will require a new mix design and an additional 28 days. The Contractor shall state the intended grout pumping temperature range. Grout mixes will be designed and approved only for the stated temperature range.

## 2.3 PIPE AND FITTINGS

All pipe shall conform to ASTM A 53/A 53M standard weight. The fittings shall be malleable iron Type I in accordance with ASME B16.3, ASME B16.5, and ASME B16.9, Class 150. Pipe shall be black steel of the diameter shown or as directed.

## PART 3 EXECUTION

### 3.1 EQUIPMENT

Drilling and grouting equipment shall be of a type, capacity, and mechanical condition suitable for the work, as approved by the Contracting Officer. Power, compressed air, all other equipment, and the layout



thereof shall meet the requirements of local, State, and Federal regulations and codes, both with respect to safety and otherwise. The use of gasoline internal combustion engines for operation of drilling and grouting equipment underground is not permitted. Internal combustion engines shall be diesel powered fitted with suitable and efficient scrubbers and in compliance with EM 385-1-1.

#### 3.1.1.1 Drilling Equipment

Standard drilling equipment of the rotary, percussion, or rotary-percussion type shall be used to perform grout hole, drain hole, and exploratory hole drilling. The use of hand-held equipment such as jackhammer or jackleg percussion-type drills for drilling holes above the horizontal is not permitted. The equipment shall be of a type and condition that will allow a drilling rate which will not delay the work and will be adequate to maintain an alignment within a tolerance of 4 percent or less of the depth.

All drilling equipment shall be properly maintained and a sufficient supply of bits, tools, and spare parts shall be kept at the job site to avoid delays. In the case of equipment breakdown, repairs shall be made promptly. Exploratory drilling shall be accomplished using rotary core drilling rigs and equipment. A standard ball bearing, swivel type, triple-tube, or double-tube core barrel shall be used at all times when drilling exploratory holes. The core barrel shall be of a length, generally 1.5 or 3 meters, 5 or 10 feet, appropriate for the working space and the type of material being drilled. Appropriate coring bits for exploratory holes and drain holes shall be NW size except wire line bits shall be NQ in size or as directed. Grout hole sizes shall be EW. A wire line system shall be used on downward inclined holes that are [15] [\_\_\_\_\_] meters [50] [\_\_\_\_\_] feet or greater in depth.

#### 3.1.1.2 Grouting Equipment

##### 3.1.1.2.1 Cement Grouting Equipment

An example of a typical grouting equipment layout is included at the end of this section. The grout plant shall be capable of supplying, mixing, stirring, and pumping the grout as specified. The plant shall have a minimum capacity of [0.11] [\_\_\_\_\_] cubic meters per minute [4] [\_\_\_\_\_] cubic feet per minute (cfm) of grout injected at a pressure not greater than [690] [\_\_\_\_\_] kPa [100] [\_\_\_\_\_] pounds per square inch (psi). It shall be maintained in first-class operating condition at all times, and any grout hole lost or damaged due to mechanical failure of equipment or inadequacy of grout supply shall be replaced at no expense to the Government. Grouting equipment to be furnished shall include the following:

- a. Air or electrically powered grout pump(s) of the progressive cavity (helical screw) type that is free of surging are capable of pumping a great range of grout consistencies, provide close control of pumping pressures and variable rates of injection, and can be easily and quickly serviced during grouting operations. A minimum of one spare grout pump and spare pump parts shall be available on site during all grouting operations.
- b. Grout mixers either mechanically driven, high-speed, shear-type tub mixers with either vertical or horizontal drum, or high-speed colloidal mixers. Mixers shall be capable of effectively mixing and stirring a capacity of at least 0.11 cubic meters 4 cubic feet of grout with water to cement ratios from 0.6:1 to 6.0:1 and achieve mixing by constant rapid circulation of grout. The mixer shall be equipped with a

suitable volume-measuring water metering device for batching water for the grout mix. The water meter shall be calibrated to read in cubic meters and thousandths cubic feet and tenths and designed in a manner that after each delivery the hands can be conveniently set back to zero. The water meter shall have a certificate of calibration from an independent laboratory. Prior to each use, the water meter shall be checked for accuracy and, if necessary, recalibrated.

c. Holding tank(s) or sump(s) of the mechanically agitated type to provide a high volume and continuous injection of grout. The sump shall be capable of holding the solids of the mix in suspension and have a capacity of at least 0.34 cubic meters 12 cubic feet of grout or three times the capacity of the mixing system. Volume of grout used from the agitator holding tank(s) or sump(s) shall be measured by a vertical graduated stick or marks at different levels in the tank(s)/sump(s).

d. Valves, pressure gauges, grout lines, header arrangements, and accessories as necessary to provide a continuous supply of grout and accurate pressure control. Grout shall be conveyed between the pump and the hole using a [single-line system consisting of a pipe or hose or combination of both extending from the pump discharge to the header at the hole collar with grout injection rate controlled by the pump speed] [ or ] [circulating double-line system composed of a supply line to the header at the hole collar and a return line from the header to the grout pump, sump, or holding tank]. Grout lines shall consist of either black steel pipe or reinforced rubber or plastic hose or a combination of both. The maximum inside diameter of all grout lines shall be 25 millimeters 1 inch. The grout injection rate for the single-line system shall be controlled by the pump speed so that settlement of solids within the lines will not occur when pumping at or above the minimum discharge capacity of the pump. The pressure in the double-line system shall be controlled by one or more valves on the control line. The distance between the hole and the pump or holding tanks shall be as short as possible to minimize the accumulation of solids and possible clogging. Pressure gauges shall be high precision, graduated with divisions not greater than 10 kPa 2 psi on the dial face, calibrated and certified correct prior to use. Gauges shall be tested for accuracy[ daily] during the work by cross comparison with a standard set of oil-filled gauges. The moving parts of all gauges shall be protected from dust, grit, and direct contact with grout.

e. Flow cone(s) to ascertain the fluidity of grout mixtures. The flow cone and method of test shall be in accordance with ASTM C 939.

f. Telephone or radio communications between the grout plant and the hole being grouted when the site conditions such as distance, noise level, or visual obstructions negatively impact on the proper control of grouting operations.

#### 3.1.2.2 Chemical Grouting Equipment

The chemical grout plant shall be of the continuous mixing and pumping type. The Contractor shall provide all chemical grouting equipment in strict compliance with the grout manufacturer or supplier recommendations for the specific grout and grout application approved by the Contracting Officer. All equipment shall be of a type, capacity, and mechanical condition suitable for doing the work, compatible with the chemical to be handled, and maintained in first-class operating conditions throughout the

job.

### 3.2 GROUT, DRAINAGE, AND EXPLORATORY HOLES

Holes through shotcrete or concrete or into the surrounding rock, for the purpose of injecting grout or air release and providing drainage, shall be at the location in the direction and to the depths shown or as directed or approved. Holes shall be formed by embedding pipe in the concrete or shotcrete at the time of placing or they shall be made by drilling through the concrete, shotcrete, or rock as indicated below for the various kinds of holes. All grout, drainage, and exploratory holes shall be drilled using only water or compressed air.

#### 3.2.1 Embedded Pipe

All metal pipe and fittings required for constructing grout holes, grout hole connections, and air vents shall be provided by the Contractor. All pipe and fittings embedded in concrete shall be cleaned thoroughly of dirt, grease, grout, and mortar immediately before embedding and shall be firmly held in position and protected from damage or displacement while the concrete is being placed. Great care shall be taken to avoid premature clogging of pipes and any pipe that becomes clogged or obstructed before completion of operations shall be cleaned out in a satisfactory manner or replaced at the expense of the Contractor. All piping required for the work shall be cut, threaded, fabricated, and installed by the Contractor, as required.

#### 3.2.2 Grout and Vent Hole Drilling

Grout and vent holes shall be located as shown and as directed. Grout holes drilled through shotcrete or concrete shall be of sufficient size to permit the caulking or grouting of short lengths of 40 millimeters 1 1/2 inch diameter pipe into the hole for attachment of the grout supply line. Grout hole diameters in rock shall be as shown within a tolerance of 6 millimeters 0.25 inch and not less than 35 millimeters 1-3/8 inch at the point of deepest penetration. The size of completed grout holes shall be checked frequently during the work to assure proper hole diameters are achieved. It is anticipated that the required depth of [ring] [tunnel and shaft] grout holes will not exceed [15] [\_\_\_\_\_] meters [50] [\_\_\_\_\_] feet. Each hole drilled shall be protected from becoming clogged or obstructed by means of a cap or other suitable device on the collar. The use of greases, "rod dope," or other lubricants on the drill rods or in grout holes will not be permitted. No core recovery will be required, and the drilling fluid shall be water or compressed air. During the drilling of grout holes, the Contractor shall take all precautionary measures to control dust, fumes, and noise in conformity with [other sections of these specifications and] the applicable local, State, and Federal laws, codes, and regulations. No drilling of tunnel and shaft or ring grout holes shall be accomplished until all contact grouting within [60] [\_\_\_\_\_] meters [200] [\_\_\_\_\_] feet has been completed.

#### 3.2.3 Drain Hole Drilling

Drainage holes shall be located as shown and as directed, and drilled through the permanent liner after all grouting from holes within [60] [\_\_\_\_\_] meters [200] [\_\_\_\_\_] feet has been completed. Drain hole diameters shall be as shown but not less than [50] [\_\_\_\_\_] millimeters [2] [\_\_\_\_\_] inches with a tolerance of 6 millimeters 0.25 inch for their full lengths.

### 3.2.4 Exploratory Hole Drilling

Exploratory drilling shall be performed as directed when required to determine the condition of the rock prior to grouting or the effectiveness of the grouting operations. Such drilling may be required at any inclination and in advance of the excavation face or from the perimeter of the tunnel or shaft. Exploratory drill hole depths may vary but will not exceed a maximum of [15][ ] meters [50][ ] feet. The entire length of each exploratory hole shall be core drilled using water or compressed air. Core size shall be [either] NW (54 millimeters 2 1/8 inch diameter) [or HQ (54 millimeters 2 1/2 inch diameter)]. Core drilling shall be performed by competent and experienced drillers and special care shall be taken to obtain cores in as good condition as possible. Core logging [will][shall] be performed by [the Government Representative][a qualified geologist experienced in core logging]. Suitable wooden core boxes [will] be furnished by the Government [as shown in Section [ ] [ ] shall be furnished by the Contractor] for core storage in a suitable area on site. Core boxes shall be protected from the weather prior to being delivered to the storage area upon completion of each exploratory drill hole. The Contractor shall place the core in the boxes in the correct sequence with each run marked by accurately labeled wooden blocks according to the measured distances in the holes. No box shall contain cores from more than one hole.

### 3.2.5 Disposal of Drill Cuttings

Drill cuttings and water produced during the drilling process shall be removed from the tunnel or shaft area on a routine basis to avoid buildup that may impede the function of temporary or permanent drainage system components such as slotted pipe, sumps, and pumps. Drill cuttings shall be disposed of at an approved location outside the tunnel or shaft.

## 3.3 GROUTING PROCEDURES

Grouting shall be done in the presence and under the direction of the Contracting Officer. Cement grout which is not injected into the hole within 1 hour after mixing (30 minutes if the mix contains fluidifier with expanding agent) shall be removed from the mixer, sump, and supply line and shall be wasted.

### 3.3.1 Washing and Pressure Testing Holes

\*\*\*\*\*  
**NOTE: Develop the appropriate form to record test results and attach it to the end of this section.**  
\*\*\*\*\*

Immediately before the injection of grout into any hole drilled for the purpose of tunnel and shaft grouting or exploratory drilling, the hole shall be thoroughly washed under pressure and then pressure tested to provide an indication of potential grout take. All intersected rock seams and crevices containing clay or other washable materials shall be washed with water and air under pressure to remove as much of these materials as practicable (normally this means until the return wash water runs clean). The maximum pressure at which air and water are introduced for any separate washing operation shall be as directed. All holes sufficiently tight to build up the maximum required pressure shall be washed at such pressure, and the washing shall continue as long as there is any increase in the rate

at which water is taken. Holes in which the required pressure cannot be reached or maintained shall be washed as long as there is any increase in the rate of flow or drop in pressure when the pump is delivering a capacity flow. Open holes in which no pressure can be built up shall be washed for a period of 5 minutes or for such a period of time as fracture-filling is being removed, as determined by the venting of muddy water through surface openings or other grout holes. Water pressure testing shall also be required in grout holes and exploration holes for the purpose of either assessing the grout take potential or the imperviousness of a grouted area. The necessary fittings, a gauge for measuring hydraulic water pressure up to [690] [\_\_\_\_\_] kPa [100] [\_\_\_\_\_] psi and a meter large enough to measure 0.14 cubic meter per minute to the nearest 0.001 cubic meter 5 cfm to the nearest 0.1 cubic foot shall be provided. The volume of water available at the drill hole shall be a minimum of [0.11] [\_\_\_\_\_] cubic meters per minute [4] [\_\_\_\_\_] cfm. Drill holes shall be tested as directed with clean water under a continuous pressure as determined in the field. After the waterline or header has been secured to the collar of the hole, water shall be pumped into the system until approximately [100] [\_\_\_\_\_] kPa [15] [\_\_\_\_\_] psi pressure is obtained. The pressure shall be maintained by control of a bypass valve and the flow test continued for 5 minutes. If no flow occurs, the pressure shall be shut in and held for 5 minutes and any pressure drop recorded. Both the hold test and the flow test may be repeated in the same interval if necessary to confirm indications of grout take or tightness of an already grouted area. During each test, record the data on the Government supplied form [ , \_\_\_\_ Form \_\_\_\_, dated \_\_\_\_ ]. Drilling, washing, and water pressure testing in previously grouted areas shall not take place before 24 hours following the completion of all the planned grouting in that particular area.

### 3.3.2 Contact Grouting

Contact grouting is defined as the injection of grout behind cast-in-place concrete lining (shaft and/or tunnel), or grouting behind the initial support system, to achieve continuous contact between the lining and the surrounding rock or soil. Tunnel plug contact grouting is also included in this definition. Contact grouting shall be done in such a manner as to ensure that all voids between the concrete or initial support members and the rock or soil face will be filled with grout. No pressure washing or testing is required prior to injecting grout. Cast-in-place concrete final lining shall have been in place at least [7] [\_\_\_\_\_] days before grouting commences. Grout shall be a [neat ] [sanded ] [[cement] [chemical] grout] mixture. The grouting of any hole shall not be terminated until all voids have been filled to the maximum extent practicable and the Government Representative directs the Contractor to stop grouting. Vent pipes, for the release of air and water during grouting of crown overbreak cavities [ which may not be filled with concrete ], shall be provided as shown and in such locations as directed or approved. The installation requirements of paragraph EMBEDDED PIPE shall apply to vent pipes. Contact grouting shall be done at the highest safe pressure as directed but initially not exceeding [69] [\_\_\_\_\_] kPa [10] [\_\_\_\_\_] psi. Grouting shall be initiated from the lower end and at the invert of a tunnel and the grout behind the liner displaced upward. Grouting in the tunnel crown area may require secondary grouting to completely fill all the void space due to overbreak. Such secondary grouting shall be done with expansive grout mixtures after the initial contact grout has been injected and set up. For shaft linings, grout holes or nipples shall be radially located and grouted from inside the shaft. Split spaced grout injection holes or nipples may be necessary in shaft liner grouting.

### 3.3.3 [Grouting Behind a Steel Liner]

This type of grouting, often called "skin" grouting, shall consist of placing neat cement grout in the annular space surrounding a steel liner or "can" to fill the void between the steel liner and the cast-in-place concrete final lining. Grouting procedures are the same as those described in paragraph CONTACT GROUTING with the following exceptions:

- a. Grout holes and sealing plugs shall be provided in the steel liner plates during fabrication. The pattern shall be as shown.
- b. Grouting equipment shall be such that sudden surges in pressure at refusal do not occur.
- c. Grout hole plugs shall be ground flush with the steel liner and finished smooth.
- d. After grouting is completed, the Government Representative will sound the liner with hammer blows to determine if all voids are filled. If directed, additional grout holes shall be drilled and tapped to receive a nipple. The use of a cutting torch to cut-in and weld-on a nipple is prohibited.]

### 3.3.4 Tunnel, shaft, and Ring Curtain Grouting

\*\*\*\*\*  
**NOTE: Tunnel, shaft, and ring curtain grouting are defined as the grouting in areas of the work including, but not limited to, ahead of the tunnel or shaft face or along any reach of tunnel or shaft to control water flows or aid in stabilizing and filling voids in the formation.**  
\*\*\*\*\*

Tunnel, shaft, and ring curtain grouting shall be accomplished at the locations shown and/or as directed. Any grout hole that is lost or damaged due to mechanical failure of equipment, inadequacy of grout supply, or Contractor error shall be replaced by another hole or holes at the Contractor's expense.

#### 3.3.4.1 Grout Injection (Cement Grout)

If the water pressure testing indicates a relatively tight hole, grouting shall be started with a thin grout mixture. For an open hole condition, the water-cement ratio shall be reduced accordingly and, with the grout pump operating as nearly as practicable at constant speed at all times, the ratio shall be reduced further, if necessary, until the required pressure has been reached. If the pressure tends to rise too high, as determined by the Government Representative, the water-cement ratio shall be changed as directed. Grout mixes shall be in the proportions directed by the Government Representative who will direct changes to suit the conditions existing in the particular grout hole. The water-cement ratio by volume will be varied to meet the characteristics of each hole as revealed by the pressure washing and testing operations and will normally range between [3.0:1.0 and 0.6:1.0][[\_\_\_\_\_] and [\_\_\_\_\_]]. Grouting pressures shall be varied as directed with conditions encountered in the respective holes. If it is found impossible to reach the required pressure after pumping a reasonable volume of grout at the minimum workable water-cement ratio, a sanded grout mix shall be used, the pumping speed shall be reduced, or

pumping stopped temporarily and intermittent grouting shall be performed, allowing sufficient time between grout injections for the grout to stiffen. If necessary to relieve premature stoppage, periodic applications of water under pressure shall be made at the direction of the Government Representative. If the desired results are not obtained with this mix, grouting in the hole shall be discontinued, if so directed. In such event, the hole shall be cleaned, the grout allowed to set, and additional drilling and grouting be done in this hole or in the adjacent area, as directed, until the desired resistance is built up. Under no conditions shall the pressure or rate of pumping be increased suddenly, because either may produce a water-hammer effect which may promote stoppage. After the grouting of any hole is completed, the pressure shall be maintained by means of a stopcock or other suitable device until the grout has set to the extent that it will be retained in the hole.

#### 3.3.4.2 Refusal

The grouting of any hole shall not be considered complete until that hole refuses to take grout at a rate of less than [0.015 cubic meter 0.5 cubic foot of solids (cement) per 1/2 hour] [0.03 cubic meter 1.0 cubic foot of solids (cement) per 10 minutes] at whatever grout mixture and pressure is being used.

#### 3.3.4.3 Grout in Drains

If leakage of grout into drains occurs, the Contractor shall immediately stop the grouting operations and remove all grout from the drains by washing, to the satisfaction of the Contracting Officer. No separate payment will be made for such work. Such stopping of grouting operations and washing of drains shall be repeated as often as required to complete the grouting.

#### 3.3.4.4 Stage Grouting

Stage grouting is the procedure by which a grout hole or a ring curtain hole is drilled, pressure tested, and grouted in successive stages within progressively deeper zones from the top of the grout hole, either from the ground surface or from the tunnel or shaft wall, to the depth shown or as directed, prepared for grouting, and then grouted. After the grout has achieved an initial set, the hole shall be washed, cleaned, and deepened and then grouted to the bottom of the next stage. If the Contractor allows the grout to harden within the grout hole, no payment will be made for redrilling the grout hole. A minimum period of [24] [\_\_\_\_\_] hours shall elapse between the completion of grouting in one stage and the start of drilling for the next stage. This procedure shall be repeated for the full depth of the grout application. Grouting pressures shall be increased [as directed] [as shown] as successive stages deepen the grout holes. Normally the grout holes shall be split spaced by locating secondary holes midway between two previously drilled and grouted primary holes, and the stage grouting process shall be repeated until the desired results are attained for the full depth of the grout application. Tertiary and succeeding series of split spaced holes shall also be drilled and grouted in stages if directed by the Government Representative.

#### 3.3.4.5 Grout Injection (Chemical Grout)

In the zones to be chemically grouted, chemical grouting shall be performed in such a way as to produce a continuous cylinder or mass of chemically grouted ground outside the excavation perimeter of the tunnel or shaft in

either soils or finely fissured rock strata, increasing the strength and reducing the permeability of the material. Grout in place shall be chemically stable and nontoxic for the environment in which it is placed. Excavation through grouted areas shall not commence until the grouting work has been completed and approved by the Government Representative. Regrouting shall be performed if the required degree of waterproofing and/or stabilization is not achieved by the first application. The method of injection shall be the continuous mixing method, with the proper amounts of grout base material, water, reactant, and accelerator automatically proportioned and continuously supplied at proper flow rates and pressures. The batch system of mixing grout shall not be permitted unless high volumes of chemical grout with shortened gel times are necessary in flowing water conditions. The base material and the water-accelerator-catalyst solution shall pass through parallel separate hoses to a suitable baffling chamber near the top of the hole. A sampling cock, to allow frequent gel time checks, shall be placed after the baffling chamber. Suitable check valves shall be placed in the grout lines at the proper locations to prevent backflow and unintentional gelations. All mixing, handling, pumping, and injection operations shall be in accordance with the manufacturer's recommendations. A technical representative of the manufacturer or supplier shall be present at the work site during the initial grouting operations.

#### 3.3.4.6 [Grout Injection Pipes

\*\*\*\*\*  
**NOTE: The following paragraph may be specified for  
grouting when it is desirable to exercise maximum  
control over the grout injection process, i.e., to  
grout or regrout at any specific depth.**  
\*\*\*\*\*

Grout pipes shall be commercially available or field fabricated as illustrated by the attached sketch. Installation shall be done with care to assure the sealing grout encapsulates the entire pipe and completely fills the annulus. Grout used to fill the annulus shall consist of portland cement, bentonite and fly ash, be thick enough to prevent infiltration into the soil or rock, and be of low strength and brittle.]

#### 3.3.5 Waste Water and Grout

Grout that cannot be placed or injected prior to initial set or maximum specified time limit shall be wasted. If such grout is mixed at the direction or approval of the Government Representative, it shall be paid for at the applicable contract unit prices for the material constituents of the wasted grout. During the progress of the work, the Contractor shall provide for adequate disposal of all wash and waste water and remove all waste grout, on a daily basis if necessary, to maintain a safe and effective grouting operation.

#### 3.4 PATCHING AND CLEANUP

Upon completion of the grouting operations, the Contractor shall remove all grout supply connections from embedded pipe to a minimum depth of 1-inch, measured from the face of the concrete [shotcrete]. Holes or depressions thus formed shall be patched with a damp-pack mortar composed of water, one part portland cement to two parts sand. One teaspoonful of aluminum powder will be added to each sack of cement used in the mortar mix to compensate for shrinkage. An unpolished, nonleafing powder of high purity and low



grease will be used. Damp-pack mortar shall be just moist enough to form a ball in the hands. It shall be thoroughly tamped into the hole using hard wooden tools. The patching shall be done in a neat workmanlike manner to provide a surface smoothness at least equal to undisturbed areas of the final lining. Exploratory holes which have not been grouted shall be packed to the full depth of the final lining with tightly rammed dry mortar and then patched as described above. Prior to final acceptance of the work, the interior surface of the final lining shall be cleaned of excess cement or chemical grout, mortar, oil, and grease to the greatest extent practicable, as determined by the Government Representative.

### 3.5 RECORDS

\*\*\*\*\*  
**NOTE: Attach ENG FORM 1836 to the end of this section.**  
\*\*\*\*\*

The Contractor shall prepare on a daily basis records of all grout hole and drain hole drilling operations, all pressure washing and pressure testing operations and all cement and chemical grouting operations. These records shall include: driller's logs of all grout holes, drain holes, and exploratory holes; pressure washing information and pressure testing results[ on Government provided form]; grouting data including time of each change of operation, rate of pumping, grouting pressures, changes in water-cement ratio, changes in proportions of additives such as fluidifier, accelerator, or sand, and amounts of various materials injected[ on Government provided form]; [core logging data on Government provided ENG FORM 1836 at a vertical scale of 1 inch equals 1 foot]; and other data considered necessary as determined by the Government Representative. Blank report forms of the type to be used are attached at the end of this specification.

### 3.6 CONTRACTOR QUALITY CONTROL

In accordance with Section 01451A CONTRACTOR QUALITY CONTROL, quality control shall be established and maintained which shall specifically include, but not be limited by, inspections to assure that:

- a. The specified qualification requirements are met.
- b. Drilling and grouting equipment is provided as specified and maintained in satisfactory condition.
- c. The required amount of [cement is][chemical grout materials are] kept on hand during grouting operations.
- d. Grouting is performed in the presence of a Government Representative.
- e. Required records are kept and submitted as specified.
- f. Accurate [cement][chemical] grout mixture proportions are maintained [as directed][as recommended by the manufacturer or supplier].
- g. Materials are properly protected from moisture and contamination after delivery and transportation to the site.

- h. Only approved materials are used.
  - i. The quantity of bulk materials used equals the computed amount.
- End of Section --