GEO-INSTITUTE OF ASCE
GROUTING COMMITTEE
JET GROUTING TASK FORCE

JET GROUTING GUIDELINE

June 2009

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The contents of this publication were developed under the auspices of the Grouting Committee of the Geo-Institute of the American Society of Civil Engineers (ASCE) which represented input from all sectors of the industry, including owners, engineers and specialty contractors. However, the contents were not developed using the American National Standards Institute (ANSI) consensus process through the ASCE Codes and Standards rules, and therefore should not be construed to be a Standard of ASCE.

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PREFACE

This document has been prepared by the Jet Grouting Task Force, a subcommittee of the Geo-Institute of the American Society of Civil Engineers (ASCE) Grouting Committee. The Jet Grouting Task Force was assembled in 2005 by the Grouting Committee to represent a cross section of the industry. Task Force members include Owners, Engineers, Consultants, and Specialty Contractors all engaged in jet grouting activities.

The intent of this document is to provide a jet grouting guideline approved by the Jet Grouting Task Force that is fair to all parties involved on a jet grouting project. This document is not intended to cover every conceivable application or requirement of jet grouting. However, it does provide standard practice requirements for qualifications, materials, equipment, testing, and production procedures for the Professional Engineer to incorporate into their project specific requirements.

The Task force has included commentary within this document. The commentary is shown in italic and appears immediately after sub-articles requiring further discussion. The commentary is here to provide a better understanding of specific language chosen for the body of the guideline and also provides alternate requirements and language that can be incorporated by the Professional Engineer.

Questions regarding this document should be directed to the Jet Grouting Task Force of the Geo-Institute of ASCE Grouting Committee.

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REVISION LOG

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8	1/5/09	All	Incorporate Peer Review Team Comments

1. GENERAL 7

1.1 Scope Project Objectives & Job Site Conditions 7
1.2 References 12
1.3 Definitions 13
1.4 Qualifications 15
1.5 Submittals 16

2. MATERIALS & EQUIPMENT 19

2.1 Materials 19
2.2 Equipment 20

3. EXECUTION 21

3.1 Test Program 21
3.2 Production Work 23
3.3 Quality Control/Quality Assurance 24
3.4 Daily Reports 25
3.5 Acceptance Criteria 26

4. MEASUREMENT AND PAYMENT 28

4.1 Measurement 28
4.2 Payment 28

1. GENERAL

Chapman/Hurley - Many comments flow out of the belief that creating a guideline that contains every clause that everyone can think of accomplishes little. Such a guideline will contain conflicting information and may place undue burden on the whole process. The objective was to agree on the essentials and include these provisions in the body of the Guideline. The commentary shown in italic provides guidance and/or clarification to the guideline writer from the collective experience of the Task Force. If a true performance specification is intended, then much of the detail could be eliminated.

1.1 Scope Project Objectives & Job Site Conditions

1.1.1 Scope

1.1.1.1 This Section specifies requirements for furnishing all labor, equipment, materials, and supplies necessary for soil stabilization by jet grouting as required to meet the project objectives specified herein.

1.1.1.2 The work shall consist of installation, monitoring and testing of Jet Grouting within the limits indicated on (.....) drawing no..... .

1.1.1.3 In connection with the Jet Grouting program, as shown on the drawings, the Jet Grouting contractor shall provide all labor, materials and equipment to accomplish the following items of work:

1.1.1.3.1 Mobilization & Demobilization
1.1.1.3.2 Drilling
1.1.1.3.3 Jet-grouting
1.1.1.3.4 Quality Assurance/Quality Control and verification
1.1.1.3.5 Spoil containment, collection and disposal.

1.1.1.4 This section is a performance type specification in so far that the contractor shall be responsible for selection of jet grouting parameters, equipment, and construction of the Jet Grouted elements to meet the design intent and the Engineer is responsible for the overall design of the jet grouted soil element or soil cement structure.

Chapman - Tailor the description of Contractor and Engineer responsibilities to the specific nature of the project, taking care to coordinate guideline language with the drawing notes and the extent of jet grouting design performed by the Engineer.

Chapman/Hurley/Kwong – This subsection is intended to mean that the Engineer is responsible for the design intent and functionality of the installed extent of jet grouting, and of the appropriateness of the specified performance requirements to meet project objectives. Selection of jet grout parameters is the expertise and responsibility of a qualified jet grout contractor with on site test program(s) and is the performance part of the guideline.

1.1.2 Project Objectives: *[Select applicable item(s) and delete the rest*]

Hurley/Burke/Kwong – The following sub-articles attempt to outline common applications for jet grouting. It is unlikely that we have captured all the possible applications of jet grouting in this document, therefore it is imperative that the Engineer clearly outline the project objective and remove irrelevant sub-articles listed below.

Burke - Jet grouting is the process planned to create cemented geometries of soil-cement product. This product will have performance requirements and will be constructed to the lines and grades shown on the drawings. Performance requirements may address strength permeability, homogeneity, or other characteristics required in order to achieve design performance. In general, overall treatment area and volume is typically all that is required to be defined, with the contractor free to select geometries and elements to treat the area and volume of soil specified. Minimum and/or maximums geometries may be specified if conditions so require.

Bruce - Homogeneity of the jet grouted soil needs to be considered for each project and specific application and should be consistent with the performance requirements and the design intent of the jet grouting.

1.1.2.1 Construction of soil cement wall as overlapping Jet-Grouted columns in a single or multiple rows, with the following characteristics:

- Minimum overlap thickness:
- Residual permeability (if required):
- Minimum Unconfined Compressive Strength (UCS):
- Vertical and horizontal tolerances:

1.1.2.2 Construction of a structural wall as overlapping Jet-grouted columns in a single or multiple rows, with the following characteristics:

- Minimum overlap thickness:
- Hydraulic conductivity (if required):
- Minimum UCS:
- Vertical and horizontal tolerances:

In each column (or every second column), a structural element (such as bar or casing or H-Pile) will be installed in accordance with Contract Documents and as specified in Sub-Section 3.2.

1.1.2.3 Construction of single pile as an isolated column, with the following characteristics:

- Minimum column diameter:
- Minimum UCS:
- Vertical and horizontal tolerances:

In each column (if required) a structural reinforcing element (such as bar, casing or H-pile) will be installed in accordance with Contract Documents and as specified in Sub-Section 3.2

1.1.2.4 Construction of a soil-cement slab as overlapping columns in the designated area, with the following characteristics:

- Minimum overlap thickness:
- Top and bottom elevations:
- Hydraulic conductivity (if required):
- Minimum UCS:

1.1.2.5 Construction of an underpinning wall (structure) as overlapping columns with the designated shape, with the following characteristic:

- Minimum overlap thickness:
- Minimum UCS:
- Vertical and horizontal tolerances:

In each column (if required) a structural reinforcing element (such as bar, casing or H-pile) will be installed in accordance with Contract Documents and as specified in Sub-Section 3.2.

1.1.2.6 Construction of a “canopy” with the aid of overlapping columns for tunneling, with the following characteristics:

- Minimum column diameter:
- Minimum overlap thickness:
- Minimum UCS:

In each column (if required) a structural reinforcing element (as bar, casing or H-pile) will be installed in accordance with Contract Documents and as specified in Sub-Section 3.2.

1.1.2.7 Construction of a mono-directional, or arch, panel soil-cement wall with the aid of overlapping panels with the following characteristics:

- Minimum reduction of permeability:
- Length of coverage for each panel:

1.1.3 Job Site Conditions

Chapman/Hurley - Often the specification for jet grouting will be part of overall Contract Documents. "Job Site Conditions" may be covered elsewhere for large public works projects. For smaller projects it is important to describe the following sub-articles. Be sure to coordinate with other specifications in the Contract Documents.

Chapman/Burke/Hurley - Add any additional job conditions, e.g., expected difficult drilling conditions that the Engineer wants to clearly communicate to the Contractor and jet grouting subcontractor and establish that the conditions should be understood and allowed for in the pricing for the jet grouting, provided they are represented in the Geotechnical Report.

Bruce - It is essential that a Geotechnical Report is provided by the Owner to all bidders. The Owner owns the site and all the structures in, on or above it.

1.1.3.1 Prior to submitting a bid price for the Jet Grouting, the grouting contractor shall conduct a site inspection; review available subsurface information (including all geotechnical engineering and data reports).

Yen - Although it is generally accepted that it is beneficial for all parties, site inspection is not necessarily a part of the technical guideline. It is often found in the bid package, however. The Owner or Owner's Engineer will frequently announce a pre-bid site visit where a briefing will be held so that bidders can inspect the job site and ask questions. One could almost assume that a prudent Contractor would request to conduct a site inspection, whether required or not.

1.1.3.2 If a building in distress is involved, a relevant pre-construction building survey shall be performed by the Engineer [*or Contractor*], prior to initiating work.

Chapman/Hurley -pre-construction survey – if jet grouting is in close proximity to existing structures, conduct a pre-construction survey to document the existing condition of the structures. Define who shall be responsible for the preconstruction survey. This survey can be covered in a general guideline for pre-construction survey for the whole project, or a specific provision included here.

1.1.3.3 If underground utilities are anticipated, the Owner shall provide a current detailed utility location plan. The Contractor will be responsible for making arrangements to have below ground utilities field located.

Kwong/Hurley – Public Agencies (Owners) will not typically accept responsibility for the location, condition, and protection of utilities. The Contractor should be given adequate allowance or bid items to probe and verify all known utilities. Unknown and hidden utilities should not be the responsibility of the Contractor.

1.1.3.4 The Owner [or Contractor] shall be responsible for obtaining any State and municipal permits (if required) and conforming to all State and local regulations.

Chapman/Hurley - In most cases the General Contractor obtains the building or construction permits. In some cases the Owner obtains the construction permits. Ensure that language here is consistent with the rest of the Contract Documents, and document any special conditions that relate to permitting.

1.1.3.5 The following shall also be listed within this section when applicable:

Maswoswe -Delete those that are not applicable and add items that are not listed

1.1.3.5.1 Environmental restrictions:

1.1.3.5.2 Noise Restrictions:

1.1.3.5.3 Work boundaries:

1.1.3.5.4 Hours for construction:

1.1.3.5.5 Hauling Restrictions:

1.1.3.5.6 Waste material handling and disposal:

1.1.3.5.7 Overhead Utilities:

1.1.3.5.8 Obstructions:

Maswoswe: Known obstructions and areas of known obstructions should be indicated in the Contract Document.

A common definition of Obstructions is: Man-made or man-placed objects or materials occurring at or below ground surface which unavoidably stops the progress of work for more than one (1) hour, despite the Contractor's diligent efforts.

Naturally occurring materials such as cobbles, boulders, dense well-bonded or other competent in situ soils are not typically considered

obstructions, but should be considered for constructability and functionality of the intended design.

Obstruction removal can be measured and paid separately by the number of hours of work, or fraction thereof per obstruction, required to remove the obstruction and resume drilling.

1.2 References

1.2.1 The most recent version of the following:

1.2.1.1 ASTM C150 or AASHTO M85 Portland Cement

1.2.1.2 ASTM D1633-00 - Standard Test Method for Compressive Strength of Molded Soil-Cement Cylinders

1.2.1.3 API Recommended Practice 13B-1: Standard Procedures for Field Testing Water Based Drilling Fluids

1.2.1.4 ACI 233R Slag Cement in Concrete and Mortar or C989-99 Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars

1.2.1.5 ASTM D 420 – 03 - Core Samples, Core Sample Testing Standard Guide to Site Characterization for Engineering, Design, and Construction Purposes.

This guide cites a host of site investigation standards, including D 2113, Practice for Diamond Core Drilling for Site Investigation. D 420 refers to all relevant ASTM documents.

1.2.1.6 ASTM D3740 – 01 Standard Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction.

This also provides guidance for testing of samples and has a good reference list of relevant ASTM's that may pertain.

1.2.1.7 ASTM C618 or AASHTO M295 - Fly Ash

1.2.1.8 AASHTO T26 Water Testing of Non-Potable Water or ASTM C1602/C 1602M - 06Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete.

This comprehensive specification on water discusses requirements for use of potable and non-potable water and ramifications, 2006.

1.2.1.9 Permeability testing - Procedure for Constant Head Hydraulic Conductivity Tests in Single Drill Holes, USBR7310-89, United States Department of the Interior, Bureau of Reclamation.

1.2.1.10 Contract Documents

Chapman/Hurley - For large projects with defined plans and guidelines that include detailed drawings, existing conditions plans, geotechnical reports, etc, it is appropriate to simply list Contract Documents or other specific related guideline sections as a reference here. This is preferred versus referencing specific drawings or guidelines for large projects because drawing numbers, specification sections, etc, tend to change.

For projects with limited plans and specifications it is important to list the following:

- *Jet grouting plan.*
- *Existing site conditions/utilities plan*
- *Project geotechnical report or geotechnical investigation information*

Yen - Geotechnical and groundwater data, including site geology, geologic profiles, material descriptions, drilling logs, laboratory testing report (particle size analysis, density, etc.), groundwater depth, hydraulic conductivity testing, and anomalous conditions should be included in the report.

Kwong - Project's geotechnical report should include a section written as a geotechnical baseline pertaining to jet grouting, and should be a part of the Contract Documents.

1.3 Definitions

1.3.1 Jet Grouting: An in-situ injection technique employed with specialized equipment that includes grout pump(s), grout mixer, drill rig, drill rods and injection monitor with horizontal radial nozzles delivering high velocity fluids to erode, mix, and stabilize in-situ soils using an engineered grout slurry.

1.3.2 Single Fluid Jet Grouting: The jet grouting technique where a single fluid, typically neat cement grout, is injected at high velocity through horizontal radial nozzle(s) to directly erode, and mix with, the in-situ soil.

1.3.3 Double Fluid Jet Grouting: The jet grouting technique where one fluid, typically neat cement grout, is injected at high velocity through horizontal radial nozzle(s) and is assisted by a second fluid, typically air, delivered through a coaxial nozzle(s), to directly erode and mix with the in-situ soil.

1.3.4 Triple Fluid Jet Grouting: The jet grouting technique where one fluid, typically water, is injected at high velocity through horizontal radial nozzle(s) and is assisted by a second fluid, typically air delivered through a coaxial nozzle(s), to erode the in-situ soil, while a separate nozzle placed lower on the monitor

delivers a third fluid, typically neat cement grout, at lower velocity to simultaneously fill the soil zone eroded by the cutting fluids (air and water).

1.3.5 Monitor (adjusted for single, double, and triple systems): A single, double, or triple fluid drill pipe attached to the end of a drilling string and designed to deliver one to three elements of the Jet Grouting process, typically air, water, and grout. The monitor has one or more injection points (nozzles).

1.3.6 Jet Grouting Supervisor: The individual on site who is in responsible charge for the jet grouting work.

1.3.7 Soil-cement: Mixture of grout slurry and in situ soils formed by the jet grouting process

1.3.8 Soil-cement element: A column, or panel (planar shape), of soil-cement formed by jet grouting, used as a component of a soil-cement structure.

1.3.9 Soil-cement structure: A single zone or block of jet grout elements that are partially or fully interlocked as indicated on the Contract Drawings. Soil cement structures shall be comprised of soil cement elements of sufficient pattern and spacing as to stabilize the soil mass within the limits shown on the Contract Drawings to meet the performance requirements specified in this Section.

Burke - According to the final draft European Code for Execution of Special Geotechnical Works; Jet Grouting, Item 3.3 – Jet grout structure is defined as an assembly of jet grout elements which are partially or fully interlocked.

1.3.10 Jet Grouted Slab: A horizontal structure formed by vertical jet grouting.

1.3.11 Jet Grouted Canopy: A structure formed by horizontal jet grouting.

1.3.12 Horizontal Jet Grouting: Treatment performed from horizontal or sub-horizontal borehole (within +/- 20 degrees from the horizontal plane).

1.3.13 Jet Grouting Parameters: Pressure of the fluid(s) within the jet grouting string; flow rate of the fluid(s); grout composition; rotational speed of the jet grouting string; and rate of withdrawal or insertion of the jet grouting string.

1.3.14 Jet Grouting String: Jointed rods with simple, double or triple inner conduit that conveys the jet grouting fluid(s) to the monitor.

1.3.15 Prejetting, precutting or prewashing: The method in which the jet grouting of an element is facilitated by a preliminary disaggregation phase consisting of jetting with water and/or other fluids.

1.3.16 Fresh-in-fresh sequence: Method that involves jet grouting elements successively without waiting for the grout to harden in the overlapping elements.

1.3.17 Primary-secondary sequence: Method in which installation of an overlapping element cannot commence before a specified hardening time or achievement of predetermined strength of the adjacent previously constructed elements(s).

1.3.18 Spoil Return: All materials including, but not limited to: liquids, semi-solids, and solids, which are discharged above ground surface during, or as a result of jet grouting.

1.3.19 Structural reinforcement: deformed steel bar, high strength steel threadbars, steel casing, or steel H-Pile.

1.3.20 UCS: Unconfined Compressive Strength at 28days

Hurley - This is intended to mean the design UCS strength at 28 days. Sampling and testing may commence on or before 28 days.

1.4 Qualifications

Due to the specialized nature of the jet grouting portion of the work, the Jet Grouting Contractor shall be pre-qualified before bidding on this work. Contractors must meet the following experience criteria;

Burke - The essence of prequalification for jet grouting contractors is this: Jet grouting is a complex high energy process with highly sophisticated equipment, managed by an experienced workforce. Safe quality work can only be performed by experienced contractors working in conditions that are similar to their previously demonstrated experience.

1.4.1 Project Experience

1.4.1.1 The Jet grouting contractor must have at least five years jet grouting experience over the last ten years; and have completed at least five (5) Jet Grouting projects, with at least two (2) projects having objectives and jet-grouting system (single, double or triple) similar to those of this project and in the same type of soil.

1.4.2 Personnel Experience

1.4.2.1 The Jet grouting supervisor must have at least three (3) years on site experience managing jet grouting field operations of similar size and scope, and must have supervised at least two (2) projects within the past five (5) years employing the jet grouting technique

proposed for this project. The supervisor shall have experience and knowledge of all aspects of jet grouting as required for the project and shall be present at the work site at all times during jet grouting operations.

Kwong - From past experience, jet grout supervisors who actually can perform the jet grout work performed much better than the "arm chair" type.

1.5 Submittals

Maswoswe/Hurley. The Owner/Engineer may require submittals to be stamped by a Professional Civil Engineer. This is required in cases where the Contractor is responsible for the design of soil cement elements or the soil cement structure.

1.5.1 The Engineer will approve or reject the Contractor's qualifications within 15 calendar days after receipt of a complete qualifications submission. Additional time required due to incomplete or unacceptable submittals will not be cause for time extension or impact or delay claims. All costs associated with incomplete or unacceptable submittals shall be borne by the Contractor.

Hurley - 15 days is a general guideline. Project circumstances may dictate an expedited review.

1.5.2 Qualifications

The following shall be submitted to the Owner's representative by the grouting contractor _____ weeks prior to the start of the work:

1.5.2.1 A list of at least (5) previously completed projects for review by the Owner's representative. The list shall include a description of the project location, scope and magnitude, and contact person with phone number.

1.5.2.2 A list of at least (2) previously completed projects of similar scope and purpose for review by the Owner's representative. The list shall include a description of the project, relative size, and contact person with phone number.

The following shall be submitted to the Owner's representative by the grouting contractor _____ weeks prior to the start of the work:

1.5.2.3 Resumes of the management, supervisory, and key personnel, for approval by the Owner's representative, in accordance with qualifications of article above.

1.5.3 Jet Grouting Equipment

The following shall be submitted to the Owner's representative by the grouting contractor _____ weeks prior to the start of the work:

1.5.3.1 Submit catalog cuts, details of grout mixers, pumps, drill rigs, and a plan view of the jet grout equipment arrangement, noting any equipment that has been modified or is of unique construction.

1.5.3.2 Submit copies of field data collection forms, including a sample copy of daily field report as described in article 3.4.

1.5.4 Grout Mix Design

The following shall be submitted to the Owner's representative by the grouting contractor _____ weeks prior to the start of the work:

1.5.4.1 Submit a mix design for the project indicating sources and types of grout materials, with volumetric proportions, and field test data from previous projects or from pre-construction grout material trials indicating set time and compressive strength achieved. If the grouting contractor intends to deviate from the materials defined in Section 2.1 of this guideline, it shall submit, evidence of satisfactory use of the proposed material from past projects with similar soil conditions or pre-construction trials.

1.5.4.2 Submit method for verifying grout mix proportions.

1.5.5 Field Demonstration Test Program

The following shall be submitted to the Owner's representative by the grouting contractor _____ weeks prior to the start of the work:

1.5.5.1 Submit details of proposed field demonstration test program for jet grouting, as specified in Section 3.1. This shall include location of test columns, layout of test pattern, jet grouting parameters to be used and variables to be tested during test program, and details of proposed quality control/quality assurance testing to meet acceptance criteria specified in article 3.5.

1.5.5.2 Following performance of the field demonstration test program and prior to beginning production jet grouting operations, submit details regarding drilling and installation of test columns, jet grouting parameters, quality control/quality assurance test results, and recommended changes to jet grouting parameters based on test program, if any.

1.5.6 Jet Grouting Procedure

The following shall be submitted to the Owner's representative by the grouting contractor _____ weeks prior to the start of the work:

1.5.6.1 Submit a general Work Procedures Plan outlining the spacing, location, depth and general sequence to achieve the specified criteria detailed in this guideline. Grout hole locations shall be dimensionally referenced to the contract drawings and shown on layout plans of suitable scale to effectively indicate the details of the layout.

1.5.6.2 A general jet grout spoil return management plan outlining waste containment methods during jet grouting and treatment and removal plans for jet grout spoil return.

Yen - It is important to distinguish between jet grouting spoil and general construction waste. Construction generated waste includes wash water, and other materials in addition to the spoil generated during the jetting process. A plan to dispose of all types of waste is important and necessary. Refer to 1.3 Definitions, 1.3.18 Spoil Return which refers exclusively to waste from the jetting process.

1.5.7 Quality assurance, quality control and verification procedures to be used for the field test and production work.

1.5.7.1 This shall include details of the procedures to obtain soil-cement samples; and catalog cuts or shop fabrication drawings of the soil-cement sampling device and curing boxes. See article 3.3.

1.5.7.2 Proposed details and formats of all required tabular and graphical data presentations that will be submitted to the Engineer during the course of the Work. This will include submittal of a copy of the reports used for data monitoring and recording, as described in article 3.3.

1.5.7.3 Submit details for permeability testing if jet grouting is used for soil-cement structures such as walls and slabs for water control purposes. Permeability testing procedures shall be in general conformance with a recognized standard.

1.5.8 Daily Reports

Within one business day after the end of a work shift, the following shall be submitted to the Owner's representative by the grouting contractor:

1.5.8.1 Submit daily reports as described in 3.4

2. MATERIALS & EQUIPMENT

2.1 Materials

The grout slurry may consist of a homogeneous mixture of any of the following materials:

2.1.1 Cement, Portland, type I or II, ASTM C-150 or AASHTO M85

2.1.2 Ground granulated blast furnace slag per ACI 233R Slag Cement in Concrete and Mortar or C989-99 Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars

2.1.3 Flyash Class C or F, ASTM C618 or AASHTO M295.

Flyash class to be utilized depends upon the intended end product. Primary concern is calcium content and Loss-on-ignition.

2.1.4 Potable Water or approved other source shall be free of deleterious materials that may adversely affect the grout.

Burke - Water that is not considered potable may produce an acceptable soil-cement element from jet grouting if for example it has a ph > 6.5 and has chemistry that does not inhibit cement hydration. Preconstruction testing of mixed grouts may be necessary using non-potable water and other sources to verify compatibility. See also ASTM C1602/C 1602M – 06 Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete. This comprehensive specification on water discusses requirements for use of potable and non-potable water and ramifications, 2006.

Maswoswe - If water is from sources other than recognized potable water suppliers, need to specify that the water shall be analyzed, e.g., in accordance with AASHTO T26, to ensure that it will have no adverse effect on the setting, hardening or durability of the mix and, where applicable, will not promote corrosion of the reinforcement.

2.1.5 Bentonite, if used, must be prehydrated for at least 12 hours, unless demonstrated hydration is achieved in less time, prior to being incorporated in the mix.

Chapman – If this is a performance spec, then the specifier shouldn't tell the contractor how to hydrate bentonite – it would be appropriate to state that bentonite should be prepared according to the supplier's recommended procedures for proper hydration, if that would address the concern without being prescriptive.

Hurley - In instances where a small amount of bentonite (less than 3% by weight of cement) is utilized in the grout mix , the contractor may demonstrate that pre-hydration is not required.

2.1.6 The ratios of the material components shall be proposed by the Contractor, confirmed during the preconstruction test program, and reviewed by the

Engineer. Once accepted, grout slurry composition shall not be changed unless requested in writing by the Contractor and accepted in writing by the Engineer.

2.2 Equipment

2.2.1 General: All equipment used for drilling boreholes; lowering, raising and rotating jet monitors; mixing grout; supplying pressurized grout and air-water to jet monitors; and jet monitors shall have proven performance records for use in Jet Grouting work, as demonstrated by the information to be submitted under Section 1.5.

2.2.2 Drilling Equipment: Use drilling equipment of a type and capacity suitable for drilling required hole diameters and depths, and lowering, raising, and rotating jet grout monitors to the depths and at the rates required to perform the work as shown on the Contract Drawings and as specified herein. The drill rig shall be equipped with automated controls to regulate and maintain consistent rod retraction rate, and rod RPM and have pressure gauges for all fluids injected.

2.2.3 Grout Mixing and Injection Equipment: Use grout mixers and holding tanks, water tanks, air compressors, and pumps of sufficient capacity to ensure adequate supply of grout, air, and water at required pressure to the Jet Grouting monitors during a full work shift to produce grout elements of the quality and dimensions necessary.

Hurley - In general grout mixers shall be high shear type and shall be equipped with load cells to accurately weigh and proportion each component of the grout mix for low flow applications. Under no circumstances shall paddle type mixers be utilized.

Burke - For projects with high grout volume demand, batch mixing may not produce sufficient demand and alternate mixing methods should be permitted with evidence that quality is not compromised.

2.2.4 Jet-Grouting pump: Shall be capable, with the nozzles proposed, of providing the required velocity and a delivery rate adequate for the execution of the work.

2.2.5 Compressor (for double and triple Jet-Grouting): Shall be capable of producing the pressure and to deliver the flow rate values proposed by the contractor depending on the parameters chosen.

2.2.6 Filling grout pump (for triple Jet-Grouting): Shall be capable of producing the pressure and to deliver the flow rate values proposed by the contractor depending on the parameter chosen.

2.2.7 Jet Grout Tools: Use Jet Grouting monitors with appropriate nozzles with the capacity suitable for producing jet grout elements in the soil types identified during Subsurface Explorations performed at the site, and of the size and depth shown on the Contract Drawings and as specified herein. The drill hole

diameter shall be sufficiently large to be a clear path for continuous spoil return during all jetting operations.

2.2.8 Equipment Instrumentation: Provide instrumentation that allows continuous monitoring and automatic recording of data throughout the jet grouting operations. As a minimum, the following shall be provided versus depth:

2.2.8.1 Pressure gauges/devices at the drilling rig to automatically record pressures of cement grout, water, and air during the grouting process.

2.2.8.2 Flow meter(s) to monitor and record the rate and total volume of grouting fluids through the grouting monitor at every element.

2.2.8.3 Devices that automatically monitor and record the rate of monitor rotation and withdrawal.

Automated instrumentation recording was a topic of much discussion. Ultimately it was decided to include as part of the guide specification to raise the standard within the industry. The task force agreed to provide a commentary on the instrumentation:

In the event that the equipment instrumentation is partially or fully inoperable, the Contractor shall work diligently with the instrumentation manufacturer or its representatives to repair and bring the instrumentation system to a fully operational state. During this time frame the Contractor shall manually record the data on the Daily Report described in Section 3.4 and the Work may continue at the discretion of the Engineer.

Chapman/Hurley - In 2007 only half or less of the jet grout drill rigs in use have the capabilities required in this guide. It was discussed that instrumentation is excellent, but is subject to failure and can be finicky in use. It was also discussed that competent inspection and good daily record-keeping provides a lot of useful data for later evaluation.

3. EXECUTION

3.1 Test Program

3.1.1 Prior to production work, a test program shall be conducted by the Contractor in accordance with the accepted work plan. The test program shall be used to optimize the various parameters including type of jet-grouting (single, double or triple), necessity of pre-jetting with water, grout mix composition, fluid(s) flows and pressures, rotational speed, retraction rate, grout, and number and size of nozzles; and confirm that resultant in situ soil-cement properties meet required design criteria.

3.1.2 The test program and its results will be observed, reviewed and approved by the Engineer. The test program shall be installed in areas near the planned production work at a location agreed upon between the Engineer and jet grouting subcontractor and in representative soils and depths anticipated to be found during production work.

3.1.3 Each test section shall consist of a plan of elements suitable to demonstrate feasibility and installed to the same bottom elevation specified for the production jet grouting work.

Hurley - In general the number and sets of columns with varying test parameters depends largely on the specific application of the jet grouting for the project. It is good practice to test three sets of injection parameters, one conservative, one aggressive and one in between. The number of columns for each set may be a single column for a pile application to perhaps three columns for a mass treatment application where the interstitial space is important.

Burke - In the performance of a cutoff wall with bottom seal, an in-situ box may be constructed and a pump test conducted to determine the effectiveness of the system. The plan for this activity and test performance shall be presented for acceptance of the Owner prior to production activities.

3.1.4 The test elements shall be exposed by excavation (where possible) and measured for geometric properties. If full-depth excavation is not feasible, drill samples or other testing method shall be used to demonstrate column size/geometry. In cases where excavation shall not be possible, a coring in the center of a single column or centroid of a group of three (3) elements shall be carried out, and three acceptable/representative specimens from each column sent to an independent Laboratory for the tests required to satisfy the criteria specified in article 3.5. Alternative testing methods may be proposed by the Contractor.

Hurley – See important commentary in regards to coring jet grouted soils in section 3.5

Maswoswe/Hurley - Coring the center is of limited value since that is the point of grout injection and will therefore always be the best part of the grout column/pile. However, coring the edge of a single column is not practical as the core hole will likely exit the column and produce erroneous results.

3.1.5 Perform Permeability testing if jet grouting is used for soil-cement structures such as walls and slabs for water control purposes. Permeability testing procedures shall be proposed by the Contractor and approved by the Engineer.

Hurley - It is recognized that permeability testing performed within a borehole cored in a jet grouted soil matrix of gravel and/or course material can be difficult because the packer assemblies require a relatively smooth borehole wall to seat properly. Leak by can easily occur. A very small increase in the amount of water injected during the permeability test can easily result in an order of magnitude difference in the test result.

The results of the borehole permeability testing can be greatly affected by the coring process and the quality of the borehole.

Hurley – For shaft bottom sealing, a better alternative may be to perform a pump test and instrument the inside and outside of the exaction to measure drawdown. See also commentary of 3.1.3

3.1.6 Subject to the results of the test program, the jet grouting contractor will present parameters selected to achieve the specified acceptance criteria for review of the Engineer. The Contractor, at their expense, may be required to repeat the construction of a test section if selected parameters fall outside test requirements. The test program shall confirm that the resultant soil-cement properties met the required design criteria prior to the Contractor proceeding with production work.

3.2 Production Work

3.2.1 Execute production jet grouting using the same jet grout tooling, materials, and procedures as demonstrated from the satisfactory set of test elements.

3.2.2 Install jet grout elements, such that continuous spoil return up the borehole annulus is achieved during all work.

3.2.3 Centerline of the elements shall not be more than 3” from the indicated plan location.

Burke - Verticality of jet grout elements is more important for some applications than others. Deviations from vertical can ordinarily be 1:100, unless obstructions exist or other difficult drilling conditions are present. Layout and overlap of columns should be considered for these conditions provided they are known to the Contractor. Proper set up is vital and drilling methods exist that can be employed to assure vertical drilling within tolerance.

Bruce - Verticality of 1:100 is not likely achievable for inclined elements.

3.2.4 The sequence of the Jet-Grouting, Primary and Secondary, fresh on fresh, pre-jetting with water is the responsibility of the jet grouting contractor and will be based on the results of the successful test program.

3.2.5 Maintain a clean site and dispose of all spoil debris, water, and spilled material during jet grouting operations.

3.2.6 Equipment for mixing, holding, and pumping grout shall be in a secure location and shall be operated to minimize spillage of material. No material will be allowed to enter storm drains or other drainage courses.

3.2.7 The grouting contractor shall monitor nearby grade, structures and utilities during all jetting work.

Chapman - Clearly describe monitoring of nearby grade, structures, and utilities required of the general contractor and/or jet grouting subcontractor. On larger projects, there will likely be a project wide monitoring requirement that could include monitoring of specific facilities of interest during jet grouting. Limits of settlement or heave should be given based on the specific ability of the structure in question to tolerate movement without distress – no-one can better define allowable movement levels than the designer who has months or years to design the project. This may consist of optical survey or monitoring of shallow of deep settlement indicators, MPBX's, etc.

3.2.8 If jet-grouting is interrupted during the execution of a column, the re-start of the jetting shall be undertaken at least 6" below the stopping point.

3.2.9 Site access shall be provided to Owner's representatives for observation of the work.

3.2.10 If reinforcement is required, the contractor shall install it in the fresh column, immediately after the completion of the jet-grouted column or the contractor shall install the reinforcement element in a borehole drilled in the hardened column, at the design location.

3.3 Quality Control/Quality Assurance

3.3.1 All Jet Grouting shall be performed in the presence of the Owner's QC/QA Representative. Owner's QC/QA representative shall be notified prior to initiating jet grouting. Monitoring and logging of Jet Grouting operations for both test areas and production work shall be performed by the jet grouting contractor.

3.3.2 The Contractor's equipment shall be configured to record and continuously show all fluid flows and pressures, rotational speed, depth and rod retraction rates. The rod retraction rate and rod RPM shall be set by the driller then automatically controlled by the drill rig during the entire jet grouting process and recorded on the jet grout installation log.

3.3.3 All the data monitored and recorded, as described in point 3.3.2, shall be made available to the Engineer in a format previously agreed on prior to the work. The Contractor shall supply the Engineer with the software used for this task. The software shall be capable of processing the data recorded and graphic in a satisfactory manner. Proposal of the software to be used shall be described in advance to the Engineer.

3.3.4 Grout mix proportions shall be measured and documented by the Contractor per the submittal requirements in section 1.5.4 above. Appropriate records shall be kept by the Contractor and submitted to the Engineer to verify that grout mixture(s) are as accepted.

3.3.5 Throughout the jet grouting operations, perform continuous coring to full depth on [ ] percent of production columns to obtain drill cores of the jet grouted

soil. The drill core will be evaluated for compliance with specific acceptance criteria defined in 3.5 herein. The contractor shall be notified immediately if the soil-cement samples do not meet the acceptance criteria outlined herein.

Hurley – Engineer to specify percent of production columns to be core drilled. The frequency depends upon the jet grouting application. 2-3% may be a reasonable frequency.

3.3.6 Perform Permeability testing of production elements if jet grouting is used for soil-cement structures such as walls and slabs for water control purposes. Permeability testing procedures shall be proposed by the Contractor and approved by the Engineer.

Hurley – Permeability testing, when performed at core locations, typically follows the same frequency outlined above for core drilling. Other methods of permeability testing may not involve core holes.

3.4 Daily Reports

3.4.1 Within one business day of a work shift, submit summary daily reports during test and production jet grouting that provide the information listed below. A sample of the report form proposed for use by the Contractor shall be submitted to the Engineer for approval prior to the start of work.

3.4.1.1 Jet grout element number.

3.4.1.2 Time and date of beginning and completion of each grout element, including interruptions to the jetting process or material supply.

3.4.1.3 Grout mix data, including mix proportions and unit weight density measurements.

3.4.1.4 Injection pressure of all fluids used to construct each grout element.

3.4.1.5 Flow rates of all fluids used to construct each grout element.

3.4.1.6 Rates of rotation and withdrawal of jet rods for each grout element.

3.4.1.7 Total grout quantity used for each element.

3.4.1.8 Top and bottom elevations of the jet grout element.

3.4.1.9 Continuous flow of spoils return.

Gazzarini - It is a good practice to verify at each column and at different elevations the value of the unit weight of the spoil. The value of

the unit weight of the spoil, in comparison with the value of the unit weight of the grout mix prepared at the plant, can give important and interesting information about the effectiveness of the Jet Grouting.

3.4.2 Continuous recording of jet grouting parameters shall be provided for each production column to verify consistency with the approved test program results.

3.5 Acceptance Criteria

Burke - Jet grouting results in a mixture of in-situ soil with a pre-engineered grout material. However, subsurface conditions are inherently discontinuous and non-homogenous which directly affects the soil cement product. It should be acknowledged that test results will therefore show variability which should be considered in the overall design and product acceptance.

Hurley - Note to Guideline writer – need to ensure that appropriate performance requirements for the project in question are specified.

3.5.1 Installation records from 3.3 and daily reports from 3.4 documenting that the approved parameters from the test program were accurately repeated for the production work

Hurley - In either case, full instrumentation or dedicated inspection is the primary quality control for the project. Once the test program has successfully demonstrated that a set of injection parameters produces an element of known geometric and mechanical properties for a given soil type, the project objective is to accurately repeat this process throughout the production work, thereby producing the same elements as the test. The full instrumentation recording or dedicated inspection, documents that the process was successfully repeated for the production work.

3.5.2 A minimum core recovery of 85% shall be provided.

Chapman/Hurley/Maswoswe - Caution should be used when specifying the acceptance criteria for 3.5.2, 3.5.3, & 3.5.4, which may not be achievable in all conditions. Specifying these criteria for temporary structure that is for the contractor's use only may not be practical. Since coring jet grouted soil may give misleading results about overall integrity, core recovery of 85% should not be the sole criteria for acceptance. Penetration rate, and observations during the core drilling process, should be considered and factored into the overall engineering judgment used for acceptance of these acceptance criteria.

Commercially available coring systems are typically employed for subsurface exploration of rock formations and provide good recovery if the jet grouted soils have relatively uniform consistency and at least "weak rock-like strength". To minimize sample disturbance, appropriate equipment such as a double or triple core barrel should be used for coring. However, coring is difficult and sometimes not an absolute measurement of in situ quality when gravels and/or course material are present in jet grouted soil. In that case, the coring process can delaminate the gravels from the low

strength jet grouted soil matrix thereby making core recovery difficult and unrepresentative of in situ conditions. If the preconstruction test columns are installed at representative locations, this problem should be observed during that test program phase of the project. The problem can be mitigated (where possible/desirable) by specifying a stronger in situ grouted soil.

Also note that coring alternating layers of treated and untreated clay is difficult because the untreated clay portion can be washed out during the coring process. Such a situation would of course be an indication of an undesirable lack of uniformity in the in situ jet grouted clay matrix that would be mitigated by better installation parameters.

Alternatively, the preconstruction test program can be used to develop QA/QC measures that rely much more on closer monitoring of production by an owner's representative, the automation of the equipment, and the automated recording of installation parameters (proven during the test program), rather than the quality of the cores in deciding whether the production work is acceptable.

Other techniques such as downhole camera/video and Pressure meter testing may be used where coring in not appropriate.

3.5.3 Permeability: [Engineer to Specify Acceptance Criteria]

Hurley - It is recognized that permeability testing performed within a borehole cored in a jet grouted soil matrix of gravel and/or course material can be difficult because the packer assemblies require a relatively smooth borehole wall to seat properly. Leak by can easily occur. A very small increase in the amount of water injected during the permeability test can easily result in an order of magnitude difference in the test result. The results of the borehole permeability testing can be greatly affected by the coring process and the quality of the borehole.

3.5.4 At least ___percent of all jet grout samples tested shall have a minimum 28-day unconfined compressive strength of ____ psi.

Hurley - The overall number of samples that meet the UCS criteria is to be determined by the Engineer who is responsible for the design intent of the jet grouting. There will always be samples that fall below the specified criteria because of the nature of the sample. We suggest 90% of samples should meet the criteria.

Kwong – Minimum grout strength should be stated in guidelines, however the minimum unconfined compressive strength at 28days should be reasonable based upon the anticipated ground and groundwater conditions.

3.5.5 Minimum overlap thickness: [Engineer to specify criteria]

3.5.6 Verticality and horizontal tolerances:[Engineer to specify criteria]

4. MEASUREMENT AND PAYMENT

4.1 Measurement

Jet Grouting shall be measured as follows:

4.1.1 Mobilization will be measured on a lump sum basis. Mobilization pay item will be deemed complete when the contractor's equipment is set up and ready to commence jet grouting operations.

4.1.2 Test program, including verification testing, will be measured on a lump sum basis. Test program will be deemed completed when the test elements are installed and approved by the Engineer.

Yen - The test program should be measured per unit price, if acceptance testing is at the discretion of the Owner or Owner's Engineer. Regardless, the test program should not become a research project which sadly has been the fate of many "test programs".

4.1.3 Jet grouting will be measured on a lump sum basis. Jet grouting will be deemed completed when all the columns are installed and approved by the Engineer.

Hurley: Alternatively jet grouting can be measured and paid on a unit price basis. This may be advantageous in situations where the final scope and/or quantity is not known. For example measurement and payment based upon a cubic yard of treated soil is common. Other alternatives may be to measure and pay per square foot of cut off wall, per square foot of shaft bottom seal area, etc

4.1.4 No separate measurement will be made for the Contractor's Quality Assurance-Quality Control Program, including verification testing, all of which shall be considered part of the Work of jet grouting. However, if coring is utilized as a verification test, coring will be measured by the linear foot of core hole.

4.2 Payment

4.2.1 Mobilization and demobilization shall be paid as a lump sum item.

4.2.2 Test Program shall be paid as a separate lump sum item.

Hurley: See commentary above on Measurement

4.2.3 Jet Grouting shall be paid as a separate lump sum item.

Hurley: See commentary above on Measurement

4.2.4 No separate payment will be made for the Contractor's Quality Assurance-Quality Control Program, including verification testing, all of which shall be considered part of the Work of jet grouting. However, if coring is utilized as a

verification test, payment will be made on a unit price basis per linear foot of core hole.