



**Minimum Guidelines for the Design and Use of Limited
Mobility Displacement Grout Injection When Performing
Subsurface Soil Stabilization in Florida Karst Environments**

LMDG-16 (revised 6/15/16)

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1. Forward

This second edition of the Minimum Guidelines for the Design and Use of Limited Mobility Displacement Grout (LMDG) Injection When Performing Subsurface Soil Stabilization in Florida Karst Environments was authored for the promotion of good practice when performing grouting in association with sinkhole stabilization for pre-existing residential and light commercial structures. This Guideline was composed through a consensus of Engineers, Geologists, and Contractors from well-respected companies with years of experience in identifying sinkhole conditions and designing appropriate stabilization plans. It is the belief of these authors that Limited Mobility Displacement (LMD) Grouting is a proven and reliable methodology for the filling of voids, and improving the density and strength of soils that have been weakened by sinkhole conditions. LMD Grouting is based on sound engineering principles, and as such competent application of the methodology should be applied.

2. Title

Minimum Guidelines for the Design and Use of Limited Mobility Displacement Grout Injection When Performing Subsurface Soil Stabilization in Florida Karst Environments.

3. Designation

This guideline is issued under the fixed designation LMDG; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates an editorial. This standard has been peer reviewed and approved by the Florida Association of Soil Stabilization Specialists for use throughout this industry.

4. Figures

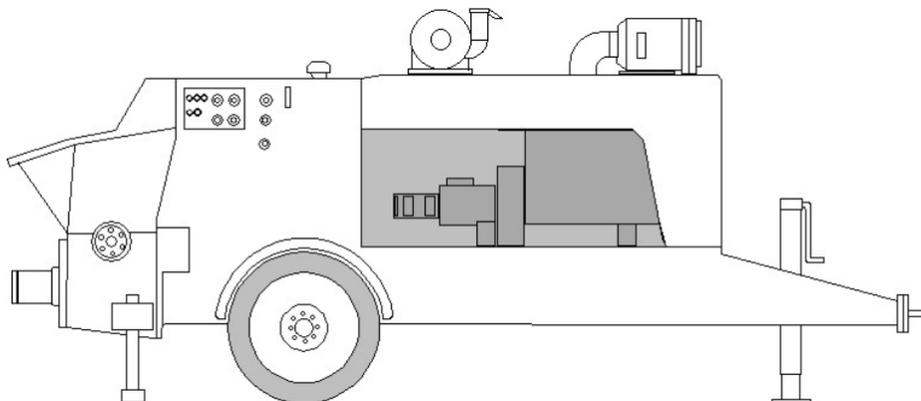


Figure 1: Detail of typical grout pump

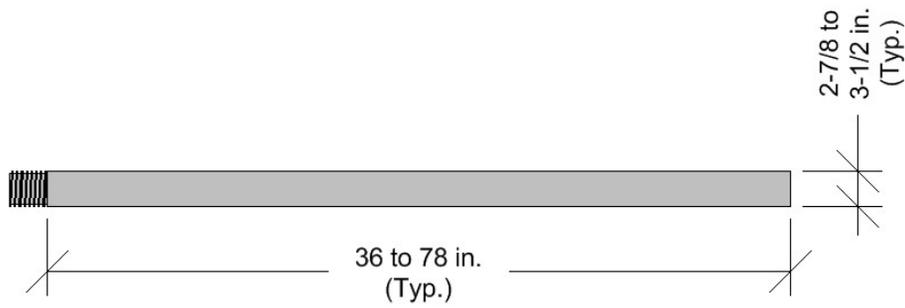


Figure 2: Detail of typical grout casing

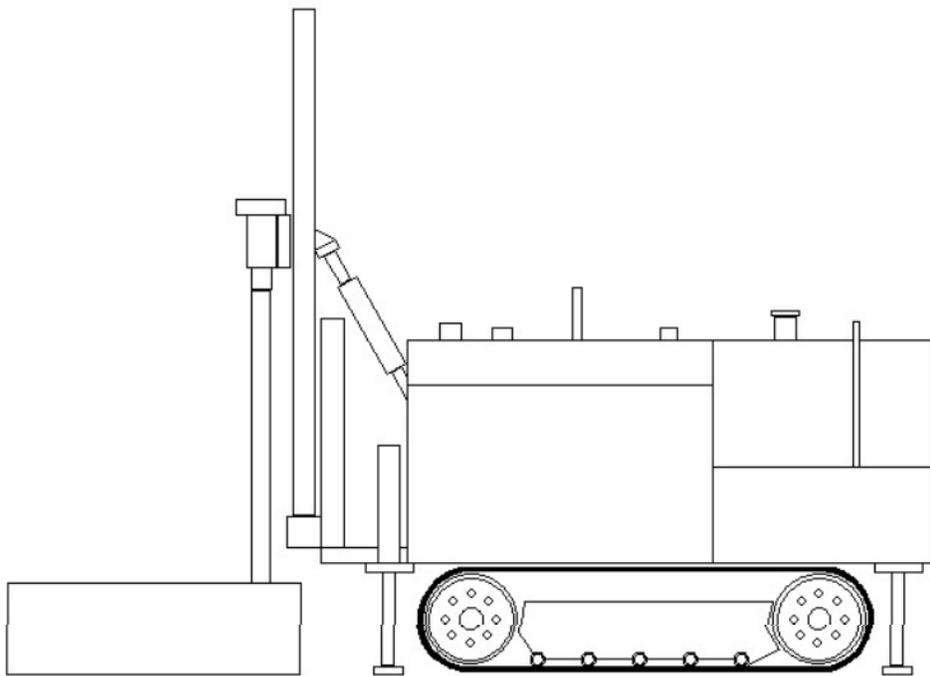


Figure 3: Detail of typical rotary wash drilling rig

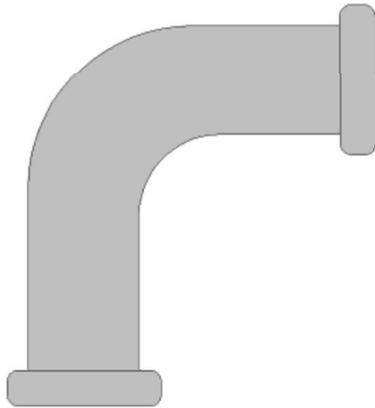


Figure 4: Detail of typical header

5. Scope

- 5.1 This guideline provides a general overview of minimum specifications and standards that should be utilized and incorporated when designing and performing soil stabilization through the use of Limited Mobility Displacement Grout (LMD) injection. The work is intended to address the risk of settlement of building structures and future sinkhole activity by treatment of foundation soils and bedrock through use of LMD Grout injection.
- 5.2 LMD grouting for sinkhole treatment involves the injection of a low-slump, grout under high pressure to fill voids, seal the bedrock surface and compact (densify) and displace soils near and above potential sinkhole conduits within the treatment area.
- 5.3 In west-central Florida, subsurface materials typically consist of porous residual and marine soils overlying weathered and solution-prone karst limestone stratum.
- 5.4 The application of LMD grouting involves the improvement of soil and rock materials in karstic areas to reduce the risk of sinkhole activity and improve soil bearing capacity.
- 5.5 This standard does not purport to address safety or geological concerns associated with the performance of Limited Mobility Displacement Grout injection. It is the responsibility of the contractor to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to installation.

6. Referenced Documents

Florida Building Code

American Concrete Institute ACI-318 - Building Code Requirements for Structural Concrete (latest edition)

ASTM Standard C143/C143M-05a, Standard Test Method for Slump of Hydraulic Cement Concrete, American Society of Testing and Materials, 2005

ASTM Standard D2487-06, Standard Classification of Soils for Engineering Purposes (United Soil Classification System), American Society of Testing and Materials, 2000

ASTM Standard D5434-03, Standard Guide for Field Logging of Subsurface Explorations of Soil and Rock, American Society of Testing and Materials, 2003

Compaction Grouting Consensus Guide, American Society of Civil Engineers, ASCE/G-I 53-10, 2010

Portland Cement Association (PCA) Design and Control of Concrete Mixtures (latest edition)

Practical Handbook of Grouting, Soil, Rock and Structures, James Warner, PE., John Wiley & Sons, Inc. 2004.

7. Terminology

7.1 Definitions of Terms Specific to this Standard:

- 7.1.1 Admixture - A chemical or mineral material other than water, aggregate, and hydraulic cement, added to the concrete immediately before or during mixing for certain desired effects.
- 7.1.2 Aggregate - Granular material, such as sand, gravel or crushed stone, used with a cementing medium to form a concrete or mortar.
- 7.1.3 Bentonite - A soft, plastic, light-colored clay formed by the chemical alteration of volcanic ash.
- 7.1.4 Casing - The steel pipe that is advanced into the ground and used for the transport of grout under pressure to a given depth.
- 7.1.5 Fly-ash - Fine particulate, essentially noncombustible refuse, carried in a gas stream from a furnace, typically a byproduct of burning coal, and used as an admixture.

- 7.1.6 Gauge Saver - A device used to prevent grout from entering the Bourdon tube of a gauge, typically consisting of a diaphragm which separates a reservoir of glycerin or light oil on the gauge side from the grout.
- 7.1.7 Header - The curved steel pipe connecting the grout hose to the top of the grout casing.
- 7.1.8 Karst - An area underlain by limestone where subsurface solutioning has produced sinkholes, caverns, and surface depression features.
- 7.1.9 Limited Mobility Displacement Grouting --Grouts that displace the substrate into which they are injected thereby improving soil densities and strength; do not travel far from the point of injection; fill voids; and do not mix with or penetrate the soil.
- 7.1.10 Positive Displacement Pumps --Pumps that will deliver the same amount of fluid per pump cycle, regardless of the pump speed or discharge pressure.
- 7.1.11 Short Stroking - Failure of the piston to travel the full length of the cylinder.

8. Materials

8.1 Grout Mixture

- 8.1.1 Shall consist of a combination of Portland cement, fine aggregate and water. Fly-ash and/or Bentonite may be added, provided the grout mixture meets strength and slump requirements. A minimum of 12% cementitious material (cement, fly-ash, slag) by weight of aggregate shall be used.
- 8.1.2 Will have a slump of 3 inches (\pm 1 inch) when measured with the current ASTM slump test (ASTM C143) at the truck. For projects with longer than typical pumping distance from the truck to the injection point, and at the discretion of the Engineer, a higher slump may be accepted at the truck provided the slump at the point of injection (at the header/hose connection) is measured periodically is measured periodically to verify the slump at the injection point is 3 inches (\pm 1 inch). The slump may be adjusted based on geological conditions at the discretion of the Engineer.
- 8.1.3 The unconfined compressive strength of the grout shall have a minimum 28-day compressive strength of 400 psi. Specimens shall be cast in either 2 x 4 inch cylinders, or 2 inch cubes, in accordance with ASTM C 31 or ASTM C 109 as applicable.

- 8.1.4 If agitated continuously, the grout may be held in the delivery truck for a maximum of 3 hours after the batch time shown on the delivery ticket, unless otherwise approved by the Engineer.
- 8.1.5 Water shall not be added to any delivered material without notification and approval of the Engineer or their representative. The quantity of any water added shall be noted on the concrete delivery ticket by the grout supplier.

8.2 Cement

- 8.2.1 The Portland cement will conform to all of the requirements of ASTM C150-78 for Portland cement type I. Cement will be stored in weather-tight enclosures, or procured in weather-tight bags to prevent against dampness and contamination. If other types of cement are utilized, they must be approved by the Engineer.

8.3 Fine Aggregates

- 8.3.1 Fine aggregate will be natural siliceous material, consisting of hard, clean, strong, durable and un-coated particles, conforming to ASTM C144-76 for aggregate for masonry mortar. The aggregate will have a fines content of not less than 10 percent and not more than 25 percent passing the No. 200 sieve.
- 8.3.2 Natural fines may be supplemented with fly-ash (type F) or Bentonite. However, clay size particles shall be limited to 5% by weight of cementitious materials.
- 8.3.3 The gradation of the mix will be such that sand blocking is eliminated at the grout working pressures specified.
- 8.3.4 The grout mix design shall be submitted to the Engineer for review prior to construction.

8.4 Water

- 8.4.1 Water used in the grout will be free of excessive amounts of salts, or other deleterious and organic material which may adversely affect the set or hydration of the cement in the grout mixture per ASTM C 1602.

9. Grout Design

9.1 Geotechnical Investigation

- 9.1.1 Geotechnical testing should be performed prior to grouting in order to gain sufficient information to design a successful grouting program.

9.2 Casing Depth

- 9.2.1 The grouting program shall be designed to ensure that the grout casing extends into competent material as directed by the Engineer. The intent in the field will be to intercept firm limestone bedrock. Care should be taken to identify the soil materials to ensure the grout pipes are not installed to depths significantly below the limestone surface.
- 9.2.2 The actual depth of an open grout point shall be confirmed by measuring with a weighted measuring tape. The measured depth shall be noted in the daily logs of the representative of the Engineer. If the depth is less than the original drilled depth, the casing shall be advanced to the proper depth prior to grouting.

9.3 Grout Point Spacing

- 9.3.1 Primary grout injection locations shall be placed around the perimeter of the primary structure at a maximum of 10 feet on center. Primary grout injection locations that are placed around the perimeter of ancillary structures (i.e. pools, decks, patio slabs) shall be spaced at a maximum of 12 feet on center.
- 9.3.2 The grout plan shall include vertical and angled points to ensure that flow of the grout occurs beneath the structure. In general, grout points located at the perimeter corners of a structure shall be in a vertical orientation.
- 9.3.3 It is the responsibility of the Contractor to contact the appropriate utility locating services to identify and locate all underground lines and conduits prior to construction. The Contractor shall determine overhead clearance requirements and holes may be relocated as necessary to avoid overhead and underground obstructions, subject to approval by the Engineer.
- 9.3.4 The contractor shall make reasonable efforts to locate all other underground utilities included but not limited to drain fields, septic tanks, irrigation systems, etc.

9.4 Pumping Sequence

- 9.4.1 The sequence in which the grout points are drilled and grouted is subject to the approval of the Engineer, and may be changed during the course of the work.
- 9.4.2 The grout pumping operations shall generally be performed in a Primary/Secondary pattern around segments of the structure, unless otherwise directed by the Engineer. This method generally uses every other grout point as a primary grout injection point, with the intermediate grout injection points as the secondary points.
- 9.4.3 Grout points near a downslope or retaining wall should typically be injected prior to those holes located at a further distance.

10. Equipment

10.1 Concrete Batcher/Mixer

- 10.1.1 The grout mixing system shall be calibrated and capable of proportioning the mix constituents to within 2% accuracy, and blending them into a homogeneous grout with uniform consistency. Calibration shall be periodically performed as requested by the Engineer.

10.2 Concrete Delivery Trucks

- 10.2.1 Use of metered trucks is discouraged due to potential inconsistency of the grout mix and difficulty in altering product ratios during batching. Metered concrete batch trucks shall be used only if the mix consistently meets the standards of section 8 of this document and the minimum unconfined compressive strength requirements.

10.3 Casing

- 10.3.1 Casing shall consist of flush joint steel casing of adequate strength to maintain the hole and to withstand the required jacking and pumping pressures. The casing should be in sections of 6 feet or less.
- 10.3.2 The casing shall have a minimum nominal inside diameter of 2 inches and a maximum inside diameter of 4 inches.

10.4 Hoses & Fittings

- 10.4.1 Either high pressure hose or a combination of hose and rigid steel lines shall be used.

- 10.4.2 The hose and pipe shall be capable of pumping at working pressures up to 1,000 psi.
- 10.4.3 Hoses and steel lines must have inside diameters of 2-inches or more.
- 10.4.4 All coupling and fittings shall be the full inside diameter of the line.

10.5 Pumps

- 10.5.1 Positive displacement piston pumps shall be used for LMD Grouting.
- 10.5.2 The pumps shall be capable of continuously delivering the specified grout materials at a pressure of at least 1,000 psi.
- 10.5.3 The pump shall be capable of pumping at rates of at least 40 cubic yards per hour (independent of the pumping pressure), unless otherwise approved by the Engineer.
- 10.5.4 The Engineer may request that the contractor periodically verify the pump stroke per cubic yard ratio during the project.
- 10.5.5 The pump shall be in good overall condition, and be capable of completely filling the grout cylinders on each stroke. The pump should be equipped with a force-feed or similar mechanism to assure complete filling of the cylinder. The contractor will not be allowed to short stroke the pump and any grout pumped during short stroking will be at the contractor's expense.
- 10.5.6 A remote off/on control for the pump shall be provided to be used at the point of grout injection.

10.6 Headers

- 10.6.1 The diameter of the header shall be no less than the same diameter of the casing.
- 10.6.2 The header shall have a port for attaching a gauge saver and pressure gauge.

10.7 Pressure Gauges

- 10.7.1 Pressure gauges shall have a minimum 3 inch diameter dial to ensure adequate visibility. The gauge shall be provided with a gauge saver, or other means to prevent grout contamination.
- 10.7.2 The gauge shall be a glycerin filled gauge with a pressure range of 0 to 1,000 psi.

- 10.7.3 A pressure gauge shall be installed at or within 25 feet of the header. A sufficient number of spare pressure gauges shall be maintained on the job site.

11. Casing Installation

- 11.1 Grout point casing should be installed by rotary wash, auger, driving, or other method to ensure advancement to the proper depths as defined by the Engineer. The method of installation should also ensure that the casing is in tight contact with the surrounding soil to keep the casing firmly in place and prevent leaking of grout around the perimeter.
- 11.2 Ponding or uncontrolled drilling fluid accumulating in the work area shall not be permitted to ensure that the jobsite is kept as clean as possible.

12. Grout Injection Procedures

- 12.1 Grout points shall be injected in ascending stages, starting at the bottom and moving upwards. No stages shall be injected until the underlying stage(s) have been completed. Individual stages shall be between 2 and 5 feet in length.
- 12.2 When performed in close proximity of a structure, grouting should not be performed at depths shallower than 10 feet and no shallower than 15 feet when the grout point is located near an in-ground pool, septic system, or other vulnerable utilities, unless otherwise directed by the Engineer.
- 12.3 Grout Injection Rate - Grout injection rates shall be designated by the engineer, as appropriate to prevent fracturing of the material being grouted. Grout injection rates are expected to range from 2 to 6 cubic feet per minute.
- 12.4 Structure Monitoring – During grouting operations, the structure shall be continuously monitored for any signs of movement - upward or downward. A surveyor's level and tripod or other electronic instruments shall be used to continuously monitor the area within a minimum of 30 feet of the grout injection point being grouted. This shall include, but is not limited to the structure, adjacent structures, slabs, decks, pools, etc.

All movements shall be noted on the grout injection log, and brought to the immediate attention of the Engineer. In certain instances, controlled heave may be a desired effect of the grouting operations; however the Engineer shall direct this.

12.5 Grout Stage Refusal Criteria

12.5.1 Grouting of any stage shall be discontinued as directed by the Engineer.

12.5.2 General refusal criteria shall be one of the following:

- A. Maximum pressure as directed by the engineer is achieved. Maximum pressures should typically range between 100 psi and 200 psi over that necessary pressure to initiate grout take (line pressure) at depths in excess of 10 feet, as soil conditions warrant. Higher or lower pressures may be required at greater depths depending on soil conditions, or as directed by the Engineer.
- B. Undesirable displacement of an adjacent structure as determined by the Engineer.
- C. Undesirable displacement of the ground surface as determined by the Engineer.
- D. The maximum volume of grout, as specified by the engineer has been injected.
- E. At the discretion of the engineer, procedures to limit grout volumes may be employed when more than 20 cubic yards of grout has been injected per 5 foot interval. If this occurs, grout injection shall temporarily cease at the injection point, the casing extracted no more than 5 feet and flushed with a minimal amount of water Grout Injection may resume after a minimum curing period of 8 hours, or as directed by the Engineer. The grout volume limitations may be adjusted based on site conditions and as directed by the Engineer. The extracted and flushed grout casing may be required to be re-drilled at the discretion of the Engineer.
- F. Tight casing is generally not considered acceptable refusal criteria but may be accepted at the discretion of the Engineer dependent on site conditions.

12.6 Access to operation and monitoring devices (i.e. pressure gauges, levels, etc.) shall be provided to the Engineer or his designated representative at all times.

12.7 Improperly Grouted Holes

12.7.1 Any grout casing that is lost or damaged, does not extend to the required depth, or if any grout point is not completed adequately as a result of equipment deficiencies, mechanical failure, poor workmanship, improper grout mix, improper drilling, mixing, or injection; the point shall be filled and replaced by a properly installed hole at no cost to the client.

12.8 Pipe Lock - Reasonable care should be taken to avoid pipe lock.

12.9 Hole Completion

- 12.9.1 After grouting has been completed to the shallowest depths allowed, the remainder of the hole shall be filled to within a few inches of the ground surface with grout.
- 12.9.2 Any depressions that may have formed during the grouting process should be filled with clean, properly compacted sand upon completion of the grout point.
- 12.9.3 Ponding or accumulation of grout material in the work area shall not be permitted to ensure that the jobsite is kept as clean as possible.

13. Testing and Quality Control

13.1 Monitoring during grouting is essential to verify proper performance of the grouting project. At a minimum, the following items shall be recorded by the Contractor for each grout injection point:

- 13.1.1 Drill depth, date, drill type, driller's name, depth to the top of competent material, recording of soil and rock materials encountered during drilling (where possible), notations of abnormalities (voids, hard drilling, loss of fluid circulation, etc.) during the drilling.
- 13.1.2 Grout consistency (slump), supplier(s) name(s); design mix verification, copies of grout tickets (from supplier).
- 13.1.3 Stroke counts, injection volume per day per pin, injection pressures, any structural movement, and notations of any abnormalities that occur during the grouting operations.

13.2 Monitoring of structural movement shall be performed by the Contractor throughout the project by a surveyor's level and various markers placed on the face of the structure(s) to a distance of 30 feet from the nearest active grout injection point to detect any movement of the structure. Additionally, stanchions and markers shall be placed near the grout injection point as needed to monitor surface heave adjacent to the structure. Other monitoring may be needed for interiors or sensitive structures.

13.3 At the completion of the work, the contractor shall provide a copy of documentation to the Engineer, including but not limited to; a summary of the drilling logs, grout injection logs for each grout injection point, field notes, concrete tickets, and an as-built grout injection location plan with any field adjustments required to perform the work.

13.4 During the course of work the representative of the Engineer shall perform slump tests in accordance with section 8.1.2 to verify the grout slump.

13.5 Cylinders or cubes of select grout samples shall be collected by the representative of the Engineer in accordance with section 8.1.3.

14. Quality Assurance

14.1 The Contractor shall have in place and continuously maintain a quality assurance program and designated quality assurance personnel onsite during all grout installation procedures.

14.2 Calibration of equipment and gauges should be performed in accordance with manufacturer specifications.

14.3 At a minimum, the Engineer (or a representative) shall maintain a daily presence onsite during all grout injection operations.

15. Construction Schedule

15.1 The Contractor shall provide manpower, tools, equipment, materials, etc., as necessary to successfully complete this project within a reasonable time schedule.

16. Protection

16.1 As previously mentioned, this guideline does not purport to address the safety concerns associated with grouting operations. It is the responsibility of the user of this guideline to establish appropriate safety and health practices and to comply with all applicable regulatory and non-regulatory requirements. However, safety is important and few safety concerns that should be followed are listed in this section.

16.2 Prior to performing any work, the Contractor shall be responsible for having buried utilities located and marked, and contacting the property owner to inquire of any additional information they may have regarding the location of buried utilities or structures.

16.3 The Contractor shall follow all applicable OSHA Standards throughout the course of the work. Installers shall wear clothing and safety equipment appropriate for the work, and/or as dictated by project specific guidelines.

16.4 All grouting equipment and material which may pose a hazard shall be barricaded when the contractor is not actively working in that area.

16.5 Work zone procedures should be implemented as appropriate.

16.6 The Engineer and/or their representative shall wear all necessary personal protection equipment while on the job site.

17. Submittals

17.1 Prior to beginning work the contractor shall submit the following information to the Engineer. Work shall not commence until the Engineer has approved the various submittals.

17.1.1 Description of all equipment the contractor proposes for use, including but not limited to mixers, grout pumps, delivery lines and appurtenances. The make and model, of each item shall be included. In the event that items will be rented, written verification shall be submitted that the unit will be available from the renter. The Engineer may request inspection of the equipment prior to work starting.

17.1.2 Description of all equipment to be used for surveys and monitoring of adjacent structures and the ground surface.

17.1.3 Names and qualifications of the lead foreman or supervisor that will be used during the drilling and grouting operations. Qualifications and experience shall be submitted to the Engineer for review.

17.1.4 Description of drilling equipment and methods to be used.

17.1.5 Description of the casing and withdrawal system to be used.

17.1.6 Grout material sources and the proposed mix design.

17.1.7 Methods and equipment for the calibration of the grout quantity pumped.

17.1.8 Statement of proposed sequence of operations.

17.1.9 Description of grout injection operations.

17.1.10 Copies of proposed drilling and grouting record forms.

18. Grout Completion Reports

18.1 The following shall be included in any Grout Completion report that is issued in regard to the grouting work:

18.1.1 Individual grout point depths, line pressures, and grout quantities for the various stages of grouting. The Contractor shall be responsible for recording this information, and shall provide these records to the Engineer. This information should be recorded daily.

- 18.1.2 Individual grout point depths, line pressures, and grout quantities for the various stages of grouting shall also be recorded by the Engineer or his representative. This information should be recorded daily.
- 18.1.3 A summary table indicating the depth of each grout point and the total quantity of grout injected into each point.
- 18.1.4 As-built drawing of grout locations.
- 18.1.5 The Engineer shall maintain copies of the concrete delivery tickets in their file.
- 18.1.6 Recommendations to allow the structure to stabilize a minimum of 60 to 90 days prior to commencement of cosmetic repairs.
- 18.1.7 Summary of any damages to adjacent structures that occurred during grouting operations.
- 18.1.8 Summary of any dropouts or ground collapses that occurred during grouting operations.
- 18.1.9 Summary of any re-drilling of grout injection points, job deficiencies, lost or damaged casing, deleted or added grout injection points, or other deviations from the project specifications or design.



19. Sample Casing Installation Log

Project Name:		Project No.:	
Project Address:		Drilling Date:	
Driller:		Equipment Used:	
Engineer:		Eng. Monitor:	
DEPTH (ft.)	SOIL DESCRIPTION		
5			
10			
15			
20			
25			
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NOTES:			

