EPA/600/R-12/584
July 2012
10/36/WQPC-SWP

Environmental Technology Verification Report
Grouts for Wastewater Collection Systems

Avanti International
AV-118 Acrylic Chemical Grout

Prepared by

C I G M A T 1994

Center for Innovative Grouting Materials and Technology
University of Houston

RTI International & NSF International

Prepared for:

EPA U.S. Environmental Protection Agency

ETV ETV ETV

Environmental Technology Verification Report

Verification of Grouts for Rehabilitation of Wastewater Collection Systems

Avanti International

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NOTICE

The U.S. Environmental Protection Agency (EPA), through its Office of Research and Development, funded and managed the research described herein under Task Order 61, *Field Verification of Drinking Water and Wastewater Systems Assessment and Rehabilitation Technologies*, of Contract No. EP-C-05-060, with RTI International (RTI). The testing was performed by the Center for Innovative Grouting Materials and Technology (CIGMAT); NSF International (NSF) provided quality assurance and other technical support. This document has been reviewed by RTI, NSF, and EPA and is recommended for public release.

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ACRONYMS AND ABBREVIATIONS

ASTM	American Society for Testing and Materials
CIGMAT	Center for Innovative Grouting Materials and Technology, University of Houston
°C	Celsius degrees
cP	Centipoise
°F	Fahrenheit degrees
DI	Deionized (water)
DQI	Data Quality Indicators
EPA	U.S. Environmental Protection Agency
ETV	Environmental Technology Verification
ft/sec	Feet per second
ft^2	Square foot (feet)
gal	Gallons
g/cm^3	Grams per cubic centimeters
g/L/g	Grams per liter per gram (of grout)
gpm	Gallon(s) per minute
GP	Generic Protocol
hr	Hour(s)
in.	Inch(es)
kg	Kilogram(s)
kg/cm^2	Kilogram(s) per square centimeter
kN	Kilonewton(s)
L	Liter
lbs	Pounds
MDL	Minimum Detection Level
min	Minute(s)
NRMRL	National Risk Management Research Laboratory
m^3	Cubic meters
m/sec	Meters per second
mg/L	Milligram(s) per liter
mL	Milliliter(s)
mm	Millimeter(s)
MPa	MegaPascal(s)
NSF	NSF International
pcf	Pounds per cubic foot
psi	Pounds per square inch
QA	Quality assurance
QC	Quality control
RH	Relative humidity
RPD	Relative Percent Difference
Room conditions	23ºC ±2ºC and relative humidity of 50% ±5%
TO	Testing Organization
VO	Verification Organization (RTI & NSF)
VTP	Verification Test Plan
WQPC	Water Quality Protection Center

ABSTRACT

Municipalities are discovering rapid degradation of infrastructures in wastewater collection and treatment facilities due to the infiltration of water from the surrounding environments. Wastewater facilities are not only wet, but also experience hydrostatic pressure conditions under normal service. Rehabilitation of these facilities by in situ methods, including use of grouting, is used to return structures to their original working conditions. Grouting is the most widely used leak-control method in small to large wastewater treatment plants and other collection systems. Application of grouts to leaking joints is considered a challenge, and performance must be evaluated using model tests representing close to actual field conditions. The grouted soil must also be durable enough to withstand the effect of severe physical and chemical environmental conditions to which it will be subjected to during the service life.

This verification evaluated Avanti International’s AV-118 Duriflex Acrylic Chemical Grout under laboratory conditions at the Center for Innovative Grouting Materials and Technology (CIGMAT) Laboratories at the University of Houston. Testing was conducted on grout and grouted sand over a period of 6 months to evaluate the grout’s performance under various simulated physical and chemical environments. Grout was characterized based on viscosity, setting time, unit weight, and leaching of organics in water by performing a series of tests. The grouted sand behavior was characterized based on the unit weight, water absorption, shrinkage, permeability, compressive strength, wet-dry cycle, and chemical resistance tests. A total of 33 grouted sand tests were performed. The compressive strength of grouted sand was determined up to 28 days of curing time. Also, the changes in length, diameter, volume, and weight of the grouted sand were studied up to 10 wet-dry cycles. A total of 48 grout and grouted sand tests were performed over the 6 month evaluation. Also, two lateral joint model tests were performed to determine the effectiveness of grouting in reducing the leak at the joints.

Testing resulted in the following measurements and observations for Avanti International's AV-118 grout:

- Model tests showed that grouting with AV-118 was effective in eliminating the leak at the lateral joint (0 water leak at 5 psi (0.35kg/cm^2) water pressure) immediately after grouting and after two wet and dry cycles over period of 1 month. The average leak rate at the 4-inch (10 cm) diameter lateral pipe joint was 1,300 gallons (4,921 liters)/day before grouting.
- The viscosity of the grout resin was 5.21 centipoise (cP). The average setting time of the grout at room temperature (21ºC) was 24.5 seconds. The average unit weight of the solid grout was 1.09 g/cm^3. The average total organic content (TOC) in the leaching water was 0.098 g/L/g of grout.
- The average unit weight of grouted sand was 2.03 g/cm^3. Based on water absorption test with three specimens, the average percentage weight and volume change in the AV-118 grouted sand was 1.12% and 1.24%, respectively. The permeability of the grouted sand was zero under a hydraulic gradient of 100. The compressive strength increased with curing time, with an average compressive strength after 28 days of curing of 29.8 psi (2.1 kg/cm^2).

- Based on the shrinkage test result from three pure grout specimens, the average weight loss was 0.04%. The average volume reduction was 0.61%.
- After the 10 wet-dry cycles, the average changes in weight, length, diameter, and volume in the grouted sand specimens were 0.05%, 0.33%, -0.21%, and 0.09%, respectively. The average unit weight of the specimens remained the same after 10 cycles. The average strength of the grout after 10 wet-dry cycles was 29.1 psi (2.0 kg/cm^2).
- After 6 months in a pH =2 solution (acid), the average change in unit weight and volume in the grouted sand specimens were 0.98% and 1.50%, respectively. After 6 months in a pH =7 solution (neutral), the average changes in unit weight and volume in the grouted sand specimens were 0.49% and 1.73%, respectively. After 6 months in a pH =10 solution (base), the average changes in unit weight and volume of the grouted sand specimens were 0.49% and 1.21%, respectively. The average compressive strengths of grouted sand in acidic, neutral, and basic environments were 18.2, 17.5 and 21.3 psi (1.28, 1.23 and 1.49 kg/cm^2), respectively.

Section 1
Introduction

1.1 ETV Purpose and Program Operation

The U.S. Environmental Protection Agency (EPA) created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The ETV Program's goal is to further environmental protection by substantially accelerating the acceptance and use of innovative, improved, and more cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations (TOs); stakeholder groups that consist of buyers, vendor organizations, consulting engineers, and regulators; and the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance (QA) protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

In cooperation with EPA, NSF International (NSF) operates the Water Quality Protection Center (WQPC), one of six centers under ETV. The WQPC has developed verification testing protocols and generic test plans that serve as templates for conducting verification tests for various technologies. Verification of the Avanti International's AV-118 Acrylic Chemical Grout was completed following the Generic Test Plan for Verification of Grouts for Wastewater Collection Systems, 2009. The Generic Plan was used to develop a product-specific verification test plan (VTP) for the Avanti International AV-118 grout.

1.2 Roles and Responsibilities

This section defines the participants in this technology verification and their roles and responsibilities.

1.2.1 Verification Organization (RTI International and NSF International)

RTI International (RTI) is the verification organization (VO) for verifications presented in this verification report, with support from NSF. The primary responsibilities of the VO are the following:

- Coordinate with the Center for Innovative Grouting Materials and Technology, University of Houston (CIGMAT), the TO, and the Vendor to prepare and approve a VTP using the generic test plan as a template and meeting all testing requirements included herein;
- Coordinate with the ETV Grouting Technical Panel, as needed, to review the VTP prior to the initiation of verification testing;

- Coordinate with the EPA WQPC Project Officer to approve the VTP prior to the initiation of verification testing;
- Review the quality systems of the TO and, subsequently, qualify the TO;
- Oversee the grouts evaluations and associated laboratory testing;
- Review data generated during verification testing;
- Oversee the development of a verification report and verification statement; and
- Provide QA oversight at all stages of the verification process.

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1.2.2 U.S. Environmental Protection Agency (EPA)

The report was developed with financial and quality assurance assistance from the ETV and WQPC programs, which are overseen by the EPA's Office of Research and Development (ORD). The ETV Program's QA Manager and the WQPC Project Officer provided administrative, technical, and QA guidance and oversight on all ETV WQPC activities, and they reviewed and approved each phase of the verification project. The primary responsibilities of EPA personnel were the following:

- Review and approve test plans, including the test/quality assurance plans (T/QAPs);
- Sign the test plan signoff sheet;
- Review and approve the verification report and verification statement; and
- Post the verification report and verification statement on the EPA ETV Web site.

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1.2.3 Testing Organization (CIGMAT Laboratories at the University of Houston)

The TO for verifications conducted under the test plan is CIGMAT Laboratories at the University of Houston. The primary responsibilities of the TO are the following:

- Coordinate with the VO and Vendor relative to preparing and finalizing the VTP;
- Sign the test plan signoff sheet;
- Conduct the technology verification in accordance with the VTP, with oversight by the VO;
- Analyze all samples collected during the technology verification process, in accordance with the procedures outlined in the VTP and referenced Standard Operating Procedures (SOPs);
- Coordinate with and report to the VO during the technology verification process;
- Provide analytical results of the technology verification to the VO; and
- If necessary, document changes in plans for testing and analysis, and notify the VO of any and all such changes before changes are executed.

CIGMAT supports faculty, research fellows, research assistants, and technicians. The CIGMAT personnel worked in groups to complete the tests described in this test plan. All the personnel reported to the Group Leader and the CIGMAT Director. The CIGMAT Director was responsible for appointing Group Leaders, who, with his approval, were responsible for drawing up the schedule for testing. Additionally, a QA Engineer, who is independent of the testing program, will be responsible for internal audits.

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1.2.4 Vendor (Avanti International)

- Provide the TO with pre-grout samples for verification;
- Complete a product data sheet prior to testing. (Refer to Appendix B);
- Provide technical support as required during the period prior to the evaluation; and
- Provide technical assistance to the TO during verification testing period, as requested.

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1.3 Background and Technical Approach

University of Houston/CIGMAT researchers have been investigating the performance of various grouts for use in wastewater facilities. Performance of grouts has been studied from setting to injection into various soils. The studies have been focused on (1) developing and characterizing grouts for various applications, (2) the behavior of grout-concrete substrate under various environmental conditions, and (3) model verification of various grout applications. The data collected on various grouts can help engineers and owners to better understand the durability of grout materials in wastewater environments.

The overall objective of this study was to systematically evaluate a grout material used in leak control. Specific testing objectives are the following:

- Evaluate the effectiveness of grout to control the leak at a simulated lateral pipe joint; and
- Determine the relevant grout and grouted sand properties.

Testing was done according to CIGMAT standards. The grout manufacturer was responsible for grouting the leaking lateral joints under the guidance of CIGMAT staff members. The grout and grouted sand specimens were evaluated over a period of 6 months.

1.4 Test Facility

The testing was performed in the CIGMAT Laboratories at the University of Houston, Houston, Texas. The CIGMAT Laboratories are located in the Central Campus of the University at 4800 Calhoun Road.

The CIGMAT Laboratories and affiliated facilities are equipped with devices that can perform all of the grouting tests described in this report. Molds are available to prepare the specimens for testing, and all the grout and grouted sand test procedures are documented in SOPs.

1.5 Objectives

The objective of this study was to evaluate Avanti International's AV-118 Duriflex Acrylic Chemical Grout for use in sewer-rehabilitation projects. Specific objectives are as follows:

- To evaluate the behavior of grout and grouted sand over a period of 6 months; and
- To determine the effectiveness of grouting in controlling water leakage at lateral joints.

Section 2
Grout Material Description

The grout material evaluated in this verification was the AV-118 Acrylic Chemical Grout from Avanti International. The grout is described on the Avanti International Web site (http://www.avantigrout.com/118sum.html) as a water solution of acrylic resins that forms a cohesive gel with the addition of catalysts.

Based on the information provided by the supplier, AV-118 Duriflex grout is used for sealing leaks in sewer pipe joints and can also be used to control water seepage in soil and rocks or cracks and joints in subgrade concrete structures. AV-101 Catalyst T+ is used as a buffer chemical and acts as a catalyst, functioning as an activator to the reaction. The primary ingredient in AV-101 Catalyst T+ is triethanolamine. AV-103 Catalyst SP is used as the initiator. AV-103 Catalyst SP is a granular material composed of sodium persulfate. It is an oxidizing agent that triggers the polymerization reaction. Generally, it is diluted to 1 to 3% in water to form an aqueous solution.

The solidified AV-118 grout gel was white in color, as shown in **Figure 2-1**.

Figure 2-1. AV-118 Grout Gel Specimens.

Section 3
Methods and Test Procedures

The testing involved characterization of grout and grouted sand. In addition, model tests were performed to determine the effectiveness of grouting in controlling leakage at a horizontal joint. The following is a summary of the methods and test procedures used in this verification.

3.1 Grout Evaluation

Properties of the grout specimen samples tested are grouped as follows:

- Working properties;
- Physical and mechanical properties;
- Durability properties; and
- Environmental properties.

More details on the tests are summarized in **Tables 3-1 and 3-2**.

Since no American Society of Testing and Materials (ASTM) test procedures exist to determine the grout and grouted sand properties, CIGMAT developed their own testing protocols, and these protocols were used.

Table 3-1. Grout Tests for Lateral Leak Repair

Properties	Tests	Conditions	Test Method Used	Lateral Repair	No. of Specimens
Working Properties	Viscosity	23ºC (73.4°F)	CIGMAT GR 6-02	X	3
	Setting (Gel) Time	23ºC	Method defined in Section 3.1.2	X	6
Physical & Mechanical Properties	Unit Weight	23ºC	CIGMAT GR 1-00	X	3
Environmental Properties	Leaching	Water	Method defined in section 3.1.2	X	3

Table 3-2. Grouted Sand Tests

Materials	Tests	Conditions	Test Method Used	Lateral Repair	Number of Tests
Physical and Mechanical Properties	Unit weight	Cured	CIGMAT GR 1-00	X	3
	Water absorbance	23ºC	CIGMAT GR 3-00	X	3
	Shrinkage	Temp, humidity	Method defined in Section 3.1.2	X	3
	Permeability	Water	CIGMAT GR 7-02	X	3
	Compressive strength	3, 7, 28 days	CIGMAT GR 2-02	X	9
Durability Properties	Wet-dry cycle	Number of cycles	CIGMAT GR 3-00	X	3
	Chemical Resistance	pH = 2, 7, 10	CIGMAT CH 2-01	X	9

3.1.1 Grout and Grouted Sand Specimen Preparation

3.1.1.1 Grout Specimens

Figure 3-1 shows the mold that was utilized to make the grout specimens. After solidification, specimens were removed from the mold and stored in labeled, sealed plastic bags for identification, protection, and to prevent moisture loss. The specimens were stored in a temperature- and humidity-controlled room at 23 ± 2°C (room temperature) and 50% ± 5% humidity.

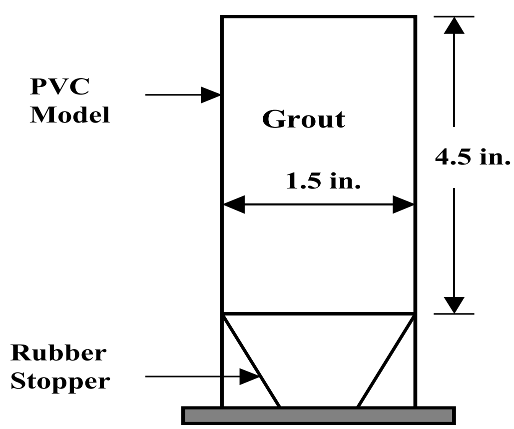


Figure 3-1. Typical mold used for preparing grout specimens.

3.1.1.2 Grouted Sand Specimens

Grouted sand specimens were prepared according to CIGMAT GS 1-02. The mold used to make the grouted sand is shown in **Figure 3-2**. Each specimen was made in a separate mold, and the amount of grout permeated was recorded by measuring the amount of grout injected. Plexiglas filters with nylon mesh were used at the inlet and outlet ends. A half-inch sand filter, separated from the specimen by nylon mesh, was used at the inlet to distribute the grout uniformly. The mold was filled with sand, and another sand filter with nylon mesh was used at the outlet (similar to inlet). Six specimens were grouted in parallel at an injection pressure of 2 psi (0.14 kg/cm^2).

After solidification, the specimens were removed from the mold and stored in sealed, labeled plastic bags in a temperature- and humidity-controlled room (23 ± 2°C and 50% ± 5% RH).

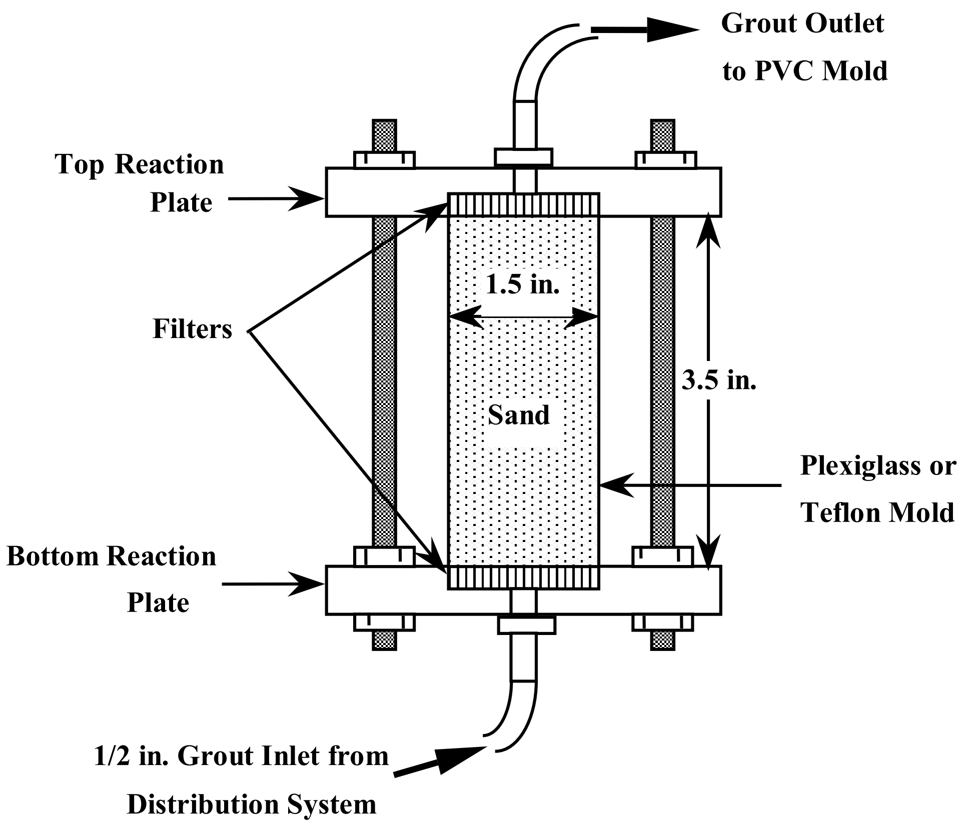


Figure 3-2. Mold for preparing grouted sand specimens.

3.1.2 Grout Curing Properties

3.1.2.1 Viscosity

Grout viscosity was evaluated using a procedure outlined in CIGMAT GR 6-02. Using a cylindrical spindle-type viscometer (Brookfield Viscometer with 8 speeds, LVT model with four spindles or equivalent), the initial viscosity of polymer grout was measured at room temperature at selected strain rates (up to 180 sec-1). Three replicate tests were conducted.

3.1.2.2 Setting (Gel) Time

No ASTM standard method is currently available to determine the gel time for acrylic chemical grouts. Subsequently, the gel time was determined based on the elapsed time from grout preparation until the grout no longer flowed from a plastic cup or beaker that was inclined slowly to 45 degrees (i.e., if the cup/beaker were filled with liquid, the surface of the liquid would remain level). Approximately 50 mL of freshly prepared grout was used. At periodic intervals, based on the observed setting of grout, the container was slowly tipped to approximately 45 degrees to determine if the grout exhibited liquid flow properties or if the grout sample had gelled and the specimen could no longer flow from the container. A total of six replicate samples of grout were analyzed.

3.1.3 Physical and Mechanical Properties

To obtain initial characterization information on the grout and grouted sand specimens, all specimens were weighed to 0.1 g using a calibrated digital balance and dimensioned (diameter and height) using a venire caliper with a least count of 0.01 mm.

3.1.3.1 Unit Weight (Density)

Solidified grout and grouted sand specimens were used to determine the unit weight (density) of the grout. The determination was completed per CIGMAT GR 1-00 for both grout and grouted sand specimens. Unit weight was calculated using the weight and volume of three specimens.

3.1.3.2 Water Absorption

Water absorption characteristics were evaluated for grouted sand specimens as outlined in standard procedure CIGMAT GR 3-00. Three grouted sand specimens were immersed in tap water (initial pH in the range of 7 to 8), and changes in weight and volume (determined by measuring specimen diameter and height) of the specimens were recorded a minimum of once per day for up to one week, until the changes in weight and volume became negligible (less than 0.5 percent of the previous weight and volume). The report for this testing included the time of immersion, the initial characteristics of the specimens, and the weight and volume changes with time.

3.1.3.3 Shrinkage

The grouted sand specimens were placed in zip lock bags and held at room temperature. Humidity was measured using a digital humidity meter. Three specimens were tested under the selected test conditions. The weight and dimensions of the specimens were measured before and after the test. The testing conditions are summarized in **Table 3-3** and were selected based on the manufacturer's recommendation.

Table 3-3. Shrinkage Test Conditions

Parts	Temperature, Duration, and storage condition
Part C	23ºC ± 2ºC for 28 days in zip lock bags (RH = 90%± 5%)

3.1.3.4 Permeability

Solidified grouted sand specimens were used to determine their permeability. Specimens were prepared in 1.5-in. (38 mm) diameter, Plexiglas/glass cylinders and permeated with water under a hydraulic gradient of 100, per CIGMAT GR 7-02. Testing was completed at room temperature and humidity. Three replicate tests were performed on grouted sand specimens.

3.1.3.5 Unconfined Compressive Strength and Stress/Strain Relationship

CIGMAT GR 2-02 was developed for testing grout and grouted sand specimens in compression under monotonically (linearly) increasing load. Compression tests were performed using screw-type machines. The specimens were trimmed to ensure smooth and parallel surfaces. Several specimens were tested at 3, 7, and 28 days following specimen preparation. The reported data include the compressive strength, modulus, and failure strain. The modulus was determined from the initial slope of the stress/strain relationship, and the failure strain was the maximum strain before the specimen failed.

3.1.4 Durability Properties

3.1.4.1 Wet-Dry Cycle

During its service life, the grouted sand could be subjected to a number of wet-dry cycles. This test was designed to determine the impact of repeated wetting and drying on the performance of grouts. A minimum of three replicate specimens were used for this test. The specimens were subjected to 10 wet-dry cycles for a total test time of 140 days, or until failure (i.e., specimen completely deteriorated). One wet/dry cycle was 14 days in duration, consisting of 7 days of water exposure followed by 7 days of dry conditions at room temperature and humidity (23 ± 2°C and 50% ± 5% RH). The water exposures were completed as described in Section 11 of CIGMAT GR 3-04, using tap water having a pH of approximately 7. Changes in length, diameter, weight, and volume of the specimens were measured daily. At the end of the 10 wet-dry cycles, the specimens were tested to determine the compressive strength of the grouted sand.

3.1.4.1 Chemical Resistance

This test evaluated the resistance of grouted sand when exposed to chemical conditions representing various environmental applications. The test results help when selecting suitable grouts for use in various chemical environments. A total of nine grouted sand specimens were prepared, and the initial weight, dimensions, color, and surface appearance of the specimens were recorded. Three specimens at each pH were fully immersed in solutions with pH 2, 7, and 10 maintained at room temperature (23 ± 2°C) for the entire exposure period. The solutions consisted of tap water with hydrochloric acid or sodium hydroxide added to achieve the pH required for the tests. The weight and volume changes were determined and recorded for three specimens at each pH after 30, 90, and 180 days, as described in Section 7.3 in CIGMAT CH 2-

01. After each evaluation, compression testing was completed for the specimens in accordance with Section 7.4 of CIGMAT CH 2-01.

3.1.5 Environmental Properties—Leaching Test

Potential contaminant leaching from solidified grout was determined by analyzing for total organic carbon (TOC) in the water exposed to the grout. Three test replicates, using cylindrical grout specimens, were performed for 7 days. The specimens were immersed in three individual exposure jars, each containing tap water. One blank container containing only the exposure water was prepared and held under the same conditions as the specimen exposure jars.

The test was conducted with three grout specimens with equal volumes of water (liquid-to-solid ratio of 1:1 (by volume)).

At the end of the exposure period, samples of water were analyzed to determine the presence of organic compounds that may have leached from the grout. The samples were analyzed for TOC.

Details of the analytical methods, required sample volumes, and sample holding are summarized in **Table 3-4**.

Table 3-4. Handling Methods and Analyses for Collected Samples

Analysis	Method[1]	Bottle Type and Size	Preservation, Holding Time	Reporting Detection Limit
TOC	SM 5310 (B or C)	Glass, two 40-mL bottles	Cool to 4ºC, pH<2 HNO_3, six months	1 mg/L

[1] *Standard Methods for the Examination of Water and Wastewater,* 20th *Edition.*

3.1.6 Model Test

Avanti International selected the model for leak control at a lateral joint for this verification study.

3.1.6.1 Model Test: Leak Control at a Lateral Joint

In order to simulate a leaking lateral joint, this model test (**Figure 3-3**) used an 8-in. (20-cm) diameter main pipe with a 4-in. (10-cm) diameter lateral pipe. Both pipes were enclosed in a sand filled rectangular steel chamber 24-inches (60 cm) wide, 24-inches (60 cm) in height, and 34-inches (86 cm) long. Both ends of the chamber had circular openings that were 8.5 inches (22 cm) in diameter for the main pipe. The top of the chamber had a circular opening for the lateral, allowing access to the leaking joint from the main pipe and the lateral. Valves on the outside of the test chamber enabled the testing apparatus to saturate the sand and bleed air from the system, and to apply water under pressure to evaluate the effectiveness of the grout application.

The procedure for preparing a lateral joint for Model Test is as follows:

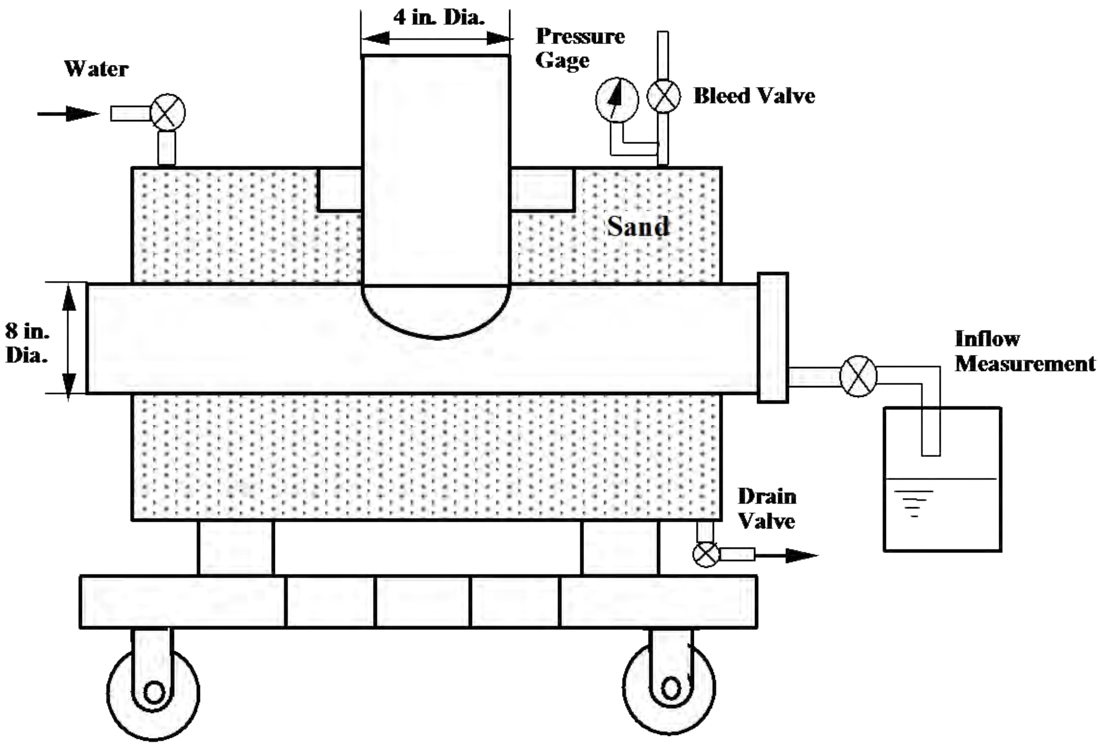
- The chamber was filled approximately halfway by freely dropping and lightly compacting the sand. The lateral pipe was then inserted in the main pipe, and the rest of the chamber was filled with sand.
- Once the chamber was filled with sand, the top cover was placed on the chamber with a rubber gasket to make the end watertight.
- Calibration curves for joint leak rate versus pressure were developed.
- The vendor injected the grout base on their protocol. The grouted joint was then tested for performance.

3.1.6.2 Model Test Procedures

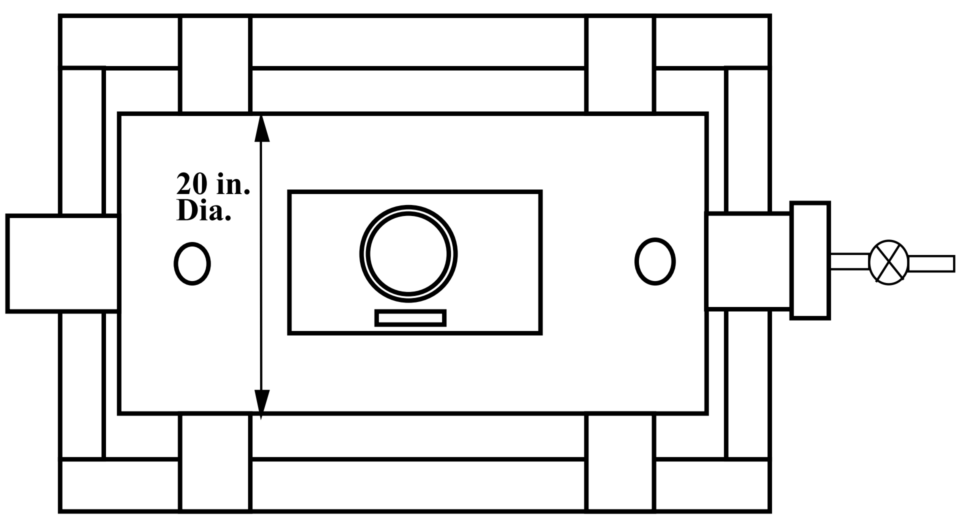
The testing procedure was conducted in duplicate. Prior to grouting, each joint was calibrated in order to develop a characteristic leak rate versus pressure relationship. The grout was injected into the wet sand by the vendor, under the supervision of the CIGMAT personnel. The time elapsed and the volume of grout used during the grouting process were recorded. During the grouting of the joint, grout samples were collected to determine the setting time and unit weight of the grout.

Once the grouted joint cured per the manufacturer’s instructions, it was subjected to the following regimen:

1. Applied hydrostatic pressure of 3 psi (0.21kg/cm^2) and held it for 5 minutes; then measured the leak rate using a graduated cylinder and a stopwatch.
2. Repeated Step 1 at a hydrostatic pressure of 4 psi (0.28 kg/cm^2).
3. Repeated Step 1 at a hydrostatic pressure of 5 psi (0.35 kg/cm^2).
4. Maintained saturated conditions for a period of 1 week.
5. Drained the water from the test chambers and allow it to stand for 1week.
6. Filled the chambers with water and repeated Step 4.
7. Repeated Step 5.
8. Determined the leak rates as described in Steps 1 through 3.



(a) Elevation View



(b) Plan View

Figure 3-3. Model configuration for testing leak control at a lateral joint.

Section 4
Results and Discussion

The testing was designed to evaluate the Avanti International AV-118 grout to control the leakage at a lateral pipe joint. A total of 48 tests were performed on grout and grouted sand specimens with two replicate of a model test.

4.1 Grout Properties

A total of 15 tests were performed to characterize the grout AV-118, and the results are summarized below, and in ***Table 4-1***. Additional details are presented in Appendix A.

4.1.1 Viscosity

This is a typical descriptive of the flow characteristics of a grout material. Viscosity is also an important parameter in determining the pumping pressure required to place the grout in the soil. Based on three tests using the Brookfield viscometer, the average viscosity of the AV-118 resin solution was 5.21 centipoise (cP).

4.1.2 Setting Time

The gelling time controls the installation time for the grout. It can also be used as a quality control (QC) measure in the field. The average gelling time of the AV-118 grout solution was 24.5 sec., with a standard deviation of 2.8 sec. and coefficient of variation of 12%.

4.1.3 Unit Weight

Unit weight can be used as a QC measure in the field. Based on three specimens, the average unit weight of the AV-118 grout was 1.09 g/cm^3, slightly denser than water.

4.1.4 Leaching

Based on three specimens, the average TOC in the water was 0.098 g/L/g of grout. These data should be considered estimated values because of data uncertainty arising from incomplete QA/QC, as discussed in Section 5.4.

Table 4-1. Summary of Working Properties of AV-118 Grout

Test Completed	Number of Specimens	Range	Mean
Viscosity (cP)	3	5.17 – 5.27	5.21
Setting Time (min)	6	21 – 30	24.5
Unit Weight (g/cm^3)	3	1.07 – 1.11	1.09
Leaching (TOC – g/L/g of grout)	3	0.096 – 0.101	0.098

4.2 Grouted Sand Properties

In characterizing the grouted sand behavior, 7 different tests were completed using 33 grouted sand specimens over a period of 180 days. Test results are summarized in the following sections, and detailed test results are summarized in Appendix B.

4.2.1 Unit Weight

Based on 3 specimens, the average unit weight of the AV-118 grouted sand was 2.03 g/cm^3. Individual specimen unit weights ranged from 1.99 to 2.09 g/cm^3.

4.2.2 Water Absorption

As presented in ***Table 4-2***, the densities of the 3 specimens did not significantly change (< 1%) over the 10-week exposure period, although there were changes in the weights and volumes. The average percentage weight and volume change in the three AV-118 grouted sand specimens was 1.12% and 1.24%, respectively.

Table 4-2. Results of Water Absorption

Exposure Time (days)	Specimen 1			Specimen 2			Specimen 3		
	Density (g/cm^3)	Δ W (%)	Δ V (%)	Density (g/cm^3)	Δ W (%)	Δ V (%)	Density (g/cm^3)	Δ W (%)	Δ V (%)
0	2.07	0.00	0.00	2.05	0.00	0.00	2.06	0.00	0.00
1	2.07	0.73	0.67	2.07	0.94	0.03	2.08	0.91	0.09
4	2.06	0.90	1.39	2.07	1.19	0.35	2.08	1.09	0.42
5	2.06	0.95	1.42	2.06	1.23	0.80	2.08	1.14	0.63
6	2.06	0.95	1.44	2.06	1.23	0.93	2.07	1.14	0.68
7	2.06	0.95	1.76	2.06	1.23	1.28	2.08	1.19	0.68

4.2.3 Shrinkage

The 3 grouted sand specimens showed losses in both volume and weight over the 28-day exposure period. The volume loss ranged from 0.20 to 1.04%, and the weight loss ranged from 0.04 to 0.05%. The average weight loss for the 3 specimens was 0.04%, and the average volume reduction was 0.61%.

4.2.4 Permeability

Three grouted sand specimens were subjected to the permeability test, and for all three, the results found the permeability to be zero under the testing conditions used in this study.

4.2.5 Compressive Strength

Specimens were tested in triplicate after 3, 7, and 28 days of curing. The data from the testing are shown in ***Table 4-3***. Although there were slight decreases from 3 to 7 days, the compressive strength and modulus increased with curing time from day 3 to day 28, while the failure strain decreased with curing time. The average compressive strength after 3 days of curing was 26.7 psi (1.87 kg/cm^2), increasing to 29.7 psi (2.08 kg/cm^2) after 28 days. The average compressive modulus after 3 days of curing was 888 psi (62.**4** kg/cm^2), which increased to 1,060 psi (74.5 kg/cm^2) after 28 days of curing time. The failure strain decreased from 5.1% on day 3 to 3.6% on day 28.

Table 4-3. Summary of Average Compressive Strength Properties

Number of Specimens	Cure Time (days)	Strength (psi)/(kg/cm^2)	Failure Strain (%)	Initial Modulus (psi)/(kg/cm^2)
3	3	26.7/1.87	5.1	888/62.4
3	7	20.7/1.45	6.6	502/35.3
5	28	29.7/2.08	3.6	1,060/74.5

4.2.6 Wet-dry Cycle

Three grouted sand specimens were exposed to 10 wet-dry cycles. The average changes in weight, length, diameter, and volume for the 3 specimens are summarized in ***Table 4-4***, and detailed results for all 3 specimens is provided in ***Table B-6*** of Appendix B. After the first wet-dry cycle, the average changes in weight, length, diameter, and volume were 0.69%, 0.08%, 0.20% and 0.33%, respectively. After the tenth wet-dry cycle, the average changes in weight, length, diameter, and volume were 0.05%, 0.33%, -0.21% and 0.09%, respectively. The average unit weight of the specimens remained essentially unchanged after 10 cycles. The average strength of the grout after 10 wet-dry cycles was 29.1 psi (2.04 kg/cm^2), about 2% less than the 28-day compressive strength of 29.7 psi (2.08 kg/cm^2), as presented in the previous Section.

Table 4-4. Wet-Dry Cycle Test Results

Cycle Number (1)	Avg ΔW (2) (%)	Avg Δ L (2) (%)	Avg Δ D (2) (%)	Avg Δ V (2) (%)	Avg Density (2) (pcf)/(kg/m^3)
1	0.69	0.08	0.20	0.33	2.07/33.1
2	0.73	0.24	0.21	0.17	2.07/33.1
3	0.69	-0.07	0.09	0.11	2.08/33.3
4	0.77	-0.58	-0.18	-0.27	2.08/33.3
5	0.67	0.08	0.29	0.51	2.07/33.1
6	0.54	0.16	-0.21	0.07	2.07/33.1
7	0.57	-0.41	0.08	-0.19	2.08/33.3
8	0.65	-0.25	0.04	0.26	2.07/33.1
9	0.05	0.47	-0.07	-0.33	2.07/33.1
10	0.05	0.33	-0.21	0.09	2.06/32.9

1 One cycle consists of 7 days of water exposure, followed by 7 days of dry exposure.
2 Average value represents conditions at the end of the cycle, compared with the initial condition.

4.2.7 Chemical Resistance

Specimens were tested in triplicate to evaluate the effects of acidic, neutral, and basic environments. After 6 months in a pH =2 solution (acid), the average changes in unit weight and volume of the 3 grouted sand specimens were 0.98% and 1.50%, respectively. After 6 months in a pH =7 solution (neutral), the average changes in unit weight and volume in the specimens were 0.49% and 1.73%, respectively. After 6 months in a pH =10 solution (base), the average changes in unit weight and volume were 0.49% and 1.21%, respectively. The average compressive strengths of grouted sand specimens in acidic, neutral, and basic environments were 18.2, 17.5, and 21.3 psi (1.28, 1.23 and 1.50 kg/cm2), respectively.

Table 4-5. Summary of Chemical Resistance Test Results

Exposure Time (days)	Weight (g)		Length (mm)		Diameter (mm)		Volume (cm^3)		Density (g/cm^3)	
	Avg	% Chg	Avg	% Chg	Avg	% Chg	Avg	% Chg	Avg	% Chg
pH 2 :										
0	216.9		94.08		37.95		106.42		2.04	
30	221.2	1.98	94.67	0.63	38.01	0.16	107.40	0.92	2.06	0.98
90	222.6	2.63	94.64	0.60	38.05	0.26	107.57	1.08	2.07	1.47
180	222.3	2.49	94.93	0.90	38.08	0.34	108.02	1.50	2.06	0.98
pH 7 :										
0	227.7		100.87		37.52		111.5 9		2.04	
30	231.9	1.84	101.19	0.32	37.68	0.43	112.90	1.17	2.06	0.98
90	232.3	2.02	101.33	0.46	37.64	0.32	113.81	1.99	2.06	0.98
180	231.9	1.84	101.64	0.76	37.69	0.45	113.44	1.66	2.05	0.49
pH 10 :										
0	233.7		100.64		37.92		113.64		2.06	
30	237.6	1.67	101.21	0.57	38.08	0.42	115.29	1.45	2.06	0.00
90	237.7	1.71	101.14	0.50	37.96	0.11	114.44	0.70	2.08	0.97
180	237.6	1.67	100.56	-0.08	38.16	0.63	115.01	1.21	2.07	0.49

4.3 Model Test

Figure 4-1 shows the schematic diagram of the Test Model. Approximately 950 pounds (430 kg) of sand were used, with the average dry unit weight of the sand being 94.5 pcf (1.51 g/cm^3). The Test Model had a main pipe of 8-inch (20 cm) diameter and lateral pipe of 4-inch (10 cm) diameter. The top of the chamber had an air outlet valve to remove air from the chamber during the saturation process. The water inlet valve was used to deliver water into the chamber, and the pressure gage was attached to the water inlet valve to measure the pressure at which the water was entering the chamber.

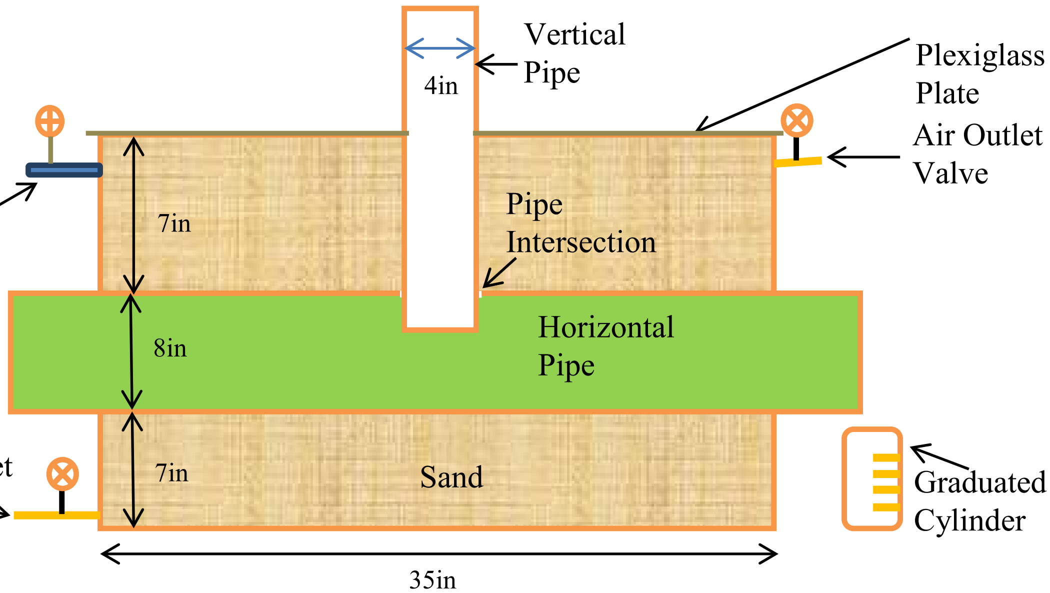


Figure 4-1. Schematic representation of the Test Model.

A water outlet valve was installed at the bottom of the chamber to drain the water from it. Two similar models (A and B) were used to verify the performance in this testing program. ***Figure 4-2*** shows the actual view of the chamber during the preparation process.

Figure 4-2. Top view of the chamber
a) Filled with sand and b) Top closed using a Plexiglas plate.

Sample Collection

Grout samples were collected at the time grouting of the Model Test was completed to determine the setting time and unit weight of the grout at that time. Eight samples were collected and it was found that the setting time was 22 seconds for each of the eight samples. Of the 12 samples collected, the unit weight of the grout varied from 1.07 g/cm^3 to 1.14 g/cm^3, with a mean unit weight of 1.10 g/cm^3.

A) Leak Test

Once the sand was placed inside the chamber, the chamber was sealed with a Plexiglas top plate, and water was injected to saturate the sand inside the chamber. Once the sand was saturated, the water pressure was maintained at 3 psi (0.21 kg/cm^2) for a period of 5 minutes, and the water leaking through the lateral joint was collected to determine the water leakage rate. The same procedure was used at water pressures of 4 psi (0.28 kg/cm^2) and 5 psi (0.35kg/cm^2). Water leakage rates with model A and model B under pressure are shown in ***Figure 4-3***.

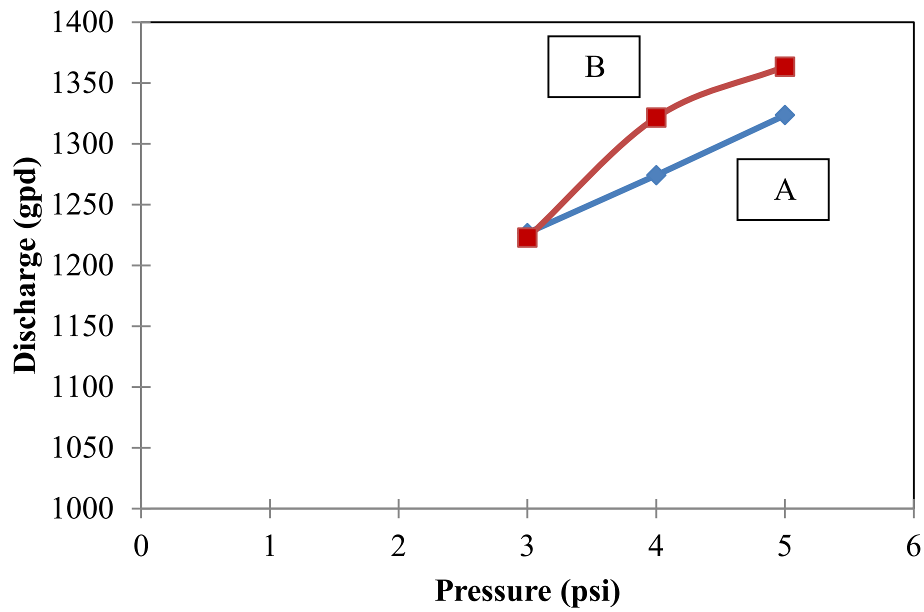


Figure 4-3. I&I leak flow discharge vs. applied pressure before grouting.

It is to be noted that the leakage rates at the pressures of 3, 4, and 5 psi (0.21, 0.28 and 0.35 kg/cm^2) in Model A were 1,227 gallons (4,644 liters) per day), 1,274 gallons (4,822 liters) per day, and 1,324 gallons (5,011 liters) per day respectively. The water leakage rates in Model B at 3, 4, and 5 psi (0.21, 0.28 and 0.35 kg/cm^2) were 1,223 gallons (4,629 liters) per day, 1,322 gallons (5,004 liters) per day and 1,364 gallons (5,163 liters) per day, respectively. ***Figure 4-4*** shows the typical water leakage at a pressure of 3 psi (0.21 kg/cm^2) in the Model before grouting.

Figure 4-4. Typical I&I Flow Leak in the Test Model

B) Grouted Joint Test

The 2 models were grouted by Avanti International. The grouting truck was brought to the CIGMAT Laboratory, and the grouting of the models was done. ***Figure 4-5*** shows the schematic of the grouting process. About 2 to 6 gallons (7.5 to 22.7 liters) of grout were injected into the models. The entire process of preparing the setup and grouting each leak joint took about 10 minutes. The room temperature at the time of grouting process varied from 22.7° to 23.6˚C, and room humidity varied from 45% to 57%.

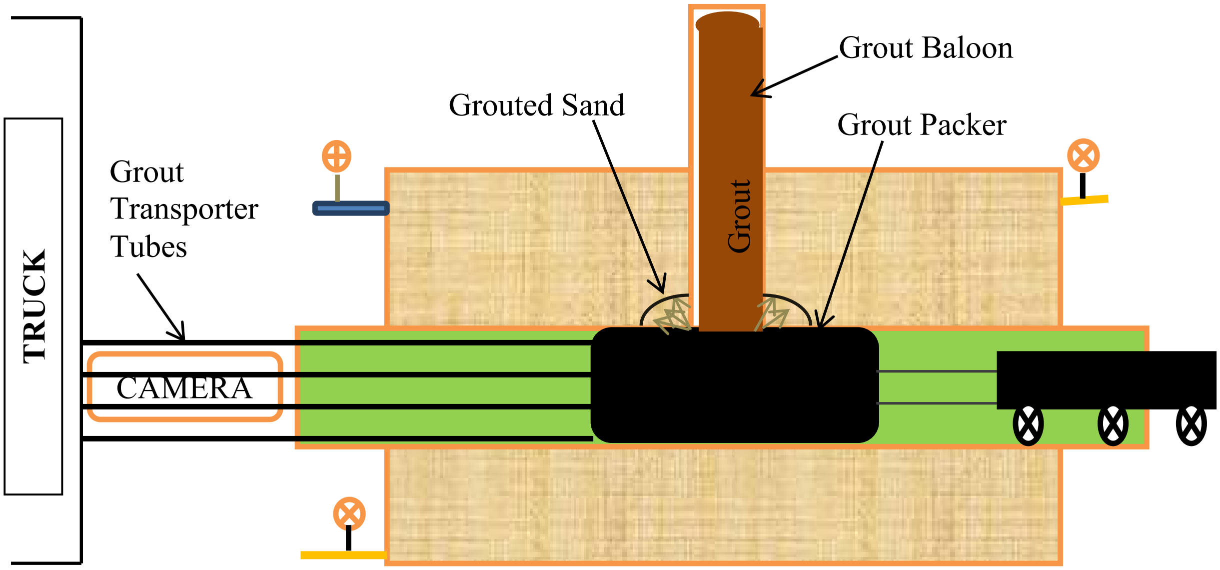


Figure 4-5. Schematic representation of the process of grouting.

The day after grouting, the lateral joints were tested for leakage at 3, 4, and 5 psi (0.21, 0.28 and 0.35 kg/cm^2), as show in ***Figure 4-6***. It was observed that there was no water leakage at 3, 4, and 5 psi (0.21, 0.28 and 0.35 kg/cm^2) pressures in either Model A or Model B. This indicated that the grout injected around the lateral joint stopped water infiltration at the lateral joint.

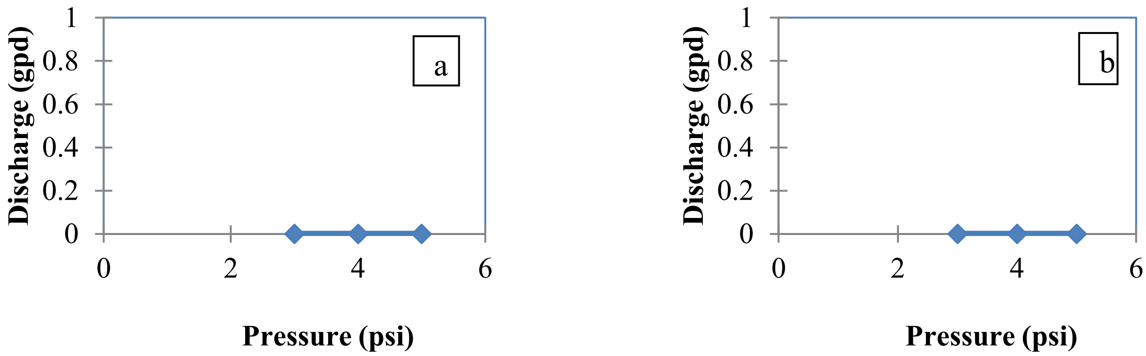


Figure 4-6. Leak rate test, day after grouting a) Model A, b) Model B.

(C) Wet-Dry Cycle:

The grouted joint was subjected to two wet-dry cycles before testing the leak at the joints again. For the first week, the chamber was kept saturated by sealing the ends of the horizontal pipe. After 7 days, the water was drained, and the model was maintained in this condition for 7 days. The chamber was saturated again for a week, and then water was drained for another week before testing for leakage at the joint.

The leakage rate at the joints was tested at pressures of 3, 4, and 5 psi (0.21, 0.28 and 0.35 kg/cm^2). The results are shown in ***Figure 4-7***. Both models had no leaks (zero) after the wet-dry cycles. Hence, the grouting was effective in completely eliminating the leakage at the lateral joint.

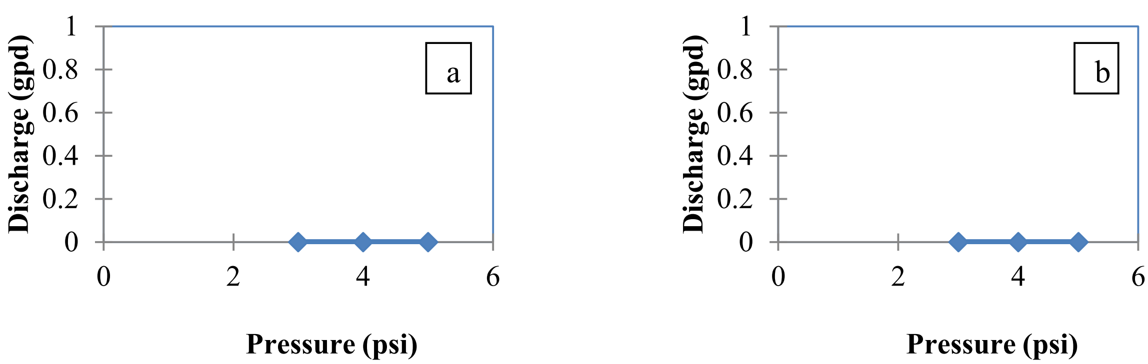


Figure 4-7. Leak rate test, after 2 wet-dry cycles a) Model A and b) Model B.

4.4 Summary of Observations

A combination of laboratory tests, including two model tests, were performed over a 6-month period on Avanti International AV-118 acrylic chemical grout to determine its effectiveness in controlling lateral leakage. These tests resulted in the following observations:

- Model tests showed that grouting with AV-118 was effective in eliminating the leakage at the lateral joint (zero water leakage at 5 psi (0.35 kg/cm^2) water pressure) immediately after grouting and after 2 wet -dry cycles over a period of 1 month. The average leakage rate at the 4-inch (10 cm) diameter lateral pipe joint was 1,300 gallons (4,921 liters)/day before grouting.
- The viscosity of the grout resin was 5.21 cP. The average setting time of the grout at room temperature (21^{o}C) was 24.5 seconds. The average unit weight of the solid grout was 1.09 g/cm^3. The average total organic content (TOC) in the leaching water was 0.098 g/L/g of grout.
- The average unit weight of grouted sand was 2.03 g/cm^3. Based on the water absorption test with 3 specimens, the average percentage weight and volume changes in the AV-118 grouted sand were 1.12% and 1.24%, respectively. The permeability of the grouted sand was zero under a hydraulic gradient of 100. The compressive strength increased with curing time, with an average compressive strength after 28 days of curing of 29.8 psi (2.1 kg/cm^2).
- Based on the shrinkage test results from 3 pure grout specimens, the average weight loss was 0.04%. The average volume reduction was 0.61%.
- After the 10 wet-dry cycles, the average changes in weight, length, diameter, and volume in the 3 grouted sand specimens were 0.05%, 0.33%, -0.21%, and 0.09%, respectively. The average unit weight of the specimens remained the same after 10 cycles. The average strength of the grout after 10 wet-dry cycles was 29.1 psi (2.0 kg/cm^2).
- After 6 months in a pH =2 solution (acid), the average changes in unit weight and volume in 3 grouted sand specimens were 0.98% and 1.50%, respectively. After 6 months in a pH =7 solution (neutral), the average changes in unit weight and volume in the 3 grouted sand specimens were 0.49% and 1.73%, respectively. After 6 months in a pH =10 solution (base), the average changes in the unit weight and volume of the 3 grouted sand specimens were 0.49% and 1.21%, respectively. The average compressive strengths of grouted sand specimens in acidic, neutral, and basic environments were 18.2, 17.5, and 21.3 psi (1.28. 1.23 and 1.50 kg/cm^2), respectively.

Section 5
QA/QC Results and Summary

The Verification Test Plan (VTP) included a Quality Assurance Project Plan (QAPP) that identified critical measurements for this verification. The verification test procedures and data collection followed the QAPP to ensure quality and integrity. CIGMAT was primarily responsible for implementing the requirements of the QAPP during testing, with oversight from NSF.

The QAPP identified requirements for preparation of the model test that would be grouted and used during the verification, along with requirements for QC indicators (i.e., representativeness, completeness and precision) and auditing.

5.1 Model Test Preparation

In this study, sand was used to prepare the grouted sand specimens and also to perform the model tests. The sand used was characterized based on particle size distribution and the results obtained for the particle size distribution tests are summarized below.

Typical grain size distribution for the sand is shown in ***Figure 5-1***. Based on three tests, the particle sizes of the sand used in this study are summarized in ***Table 5-1***.

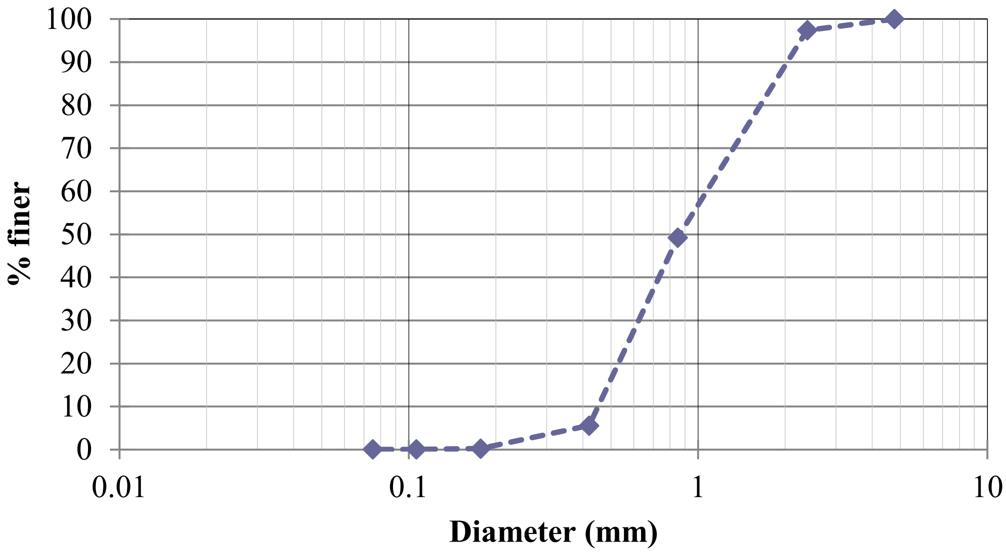


Figure 5-1. Grain size distribution curve for sand used in grouting tests.

Table 5-1. Summary of Particle Size Distribution for Sand[a]

Tests	**d10** (mm)	**d50** (mm)	**d90** (mm)	Cu	Cc
1	0.45	0.87	2.0	2.44	0.78
2	0.35	1.07	2.1	4.00	0.94
3	0.36	1.1	2.1	3.92	0.99
Mean	0.39	1.01	2.07	3.45	0.90
Std. Dev	0.045	0.10	0.05	0.72	0.09
COV	0.12	0.10	0.02	0.21	0.10

[a] d10 = sieve size through which 10% of sample passes; d50 = sieve size through which 50% of sample passes; d90 = sieve size through which 90% of sample passes; Cu = coefficient of uniformity; Cc = coefficient of concavity.

5.2 Quality Control Indicators

5.2.1 Representativeness

Representativeness of the samples during this evaluation was addressed by CIGMAT personnel following consistent procedures in preparing specimens, having the vendor apply grouts to the specimens, and following CIGMAT SOPs in curing and testing of the grouted specimens.

5.2.2 Completeness

The numbers of grout and grouted sand specimens to be evaluated during the verification were described in the VTP, and in ***Tables 3-1*** and ***3-2*** of this report. The number of specimens required for each of the tests to be completed during the verification testing was satisfied.

Two replicate model tests were completed during this evaluation, meeting the completeness goal in the VTP.

5.2.3 Precision

As specified in Standard Methods (Method 1030 C), precision is specified by the standard deviation of the results of replicate analyses. The overall precision of a study includes the random errors involved in sampling as well as the errors in sample preparation and analysis. The VTP did not establish objectives for this measure. For the most part, only three samples were prepared, or exposures were completed under different conditions, making comparison impractical.

5.2.4 Accuracy

Few of the measurements made during this evaluation have references for measurement of accuracy. Matrix spike and duplicate samples, called for in the VTP, were not completed for the TOC analyses due to test facility oversight. Subsequently, percent recovery and relative percent difference (RPD) cannot be determined for the TOC analysis.

5.3 Audit Reports

NSF conducted two audits of the CIGMAT Laboratories prior to the verification test. The first laboratory audit, completed by an independent contractor, found that CIGMAT had the necessary equipment, procedures, and facilities to perform the verification tests described in the VTP, but identified a number of improvements that could be made to provide the documentation to support testing outcomes. In the second audit, NSF personnel found that systems were in place to record laboratory data and supporting QA data obtained during the tests. Specialized log sheets had been prepared for each of the procedures, and these data sheets are stored with the Study Director. This is important because some of these tests are performed over several months, with extended periods between testing.

One of the primary weaknesses identified in the CIGMAT systems was in documentation of the calibration and maintenance of the basic equipment. It was quite clear that calibration of the balances, pH meters, pulse velocity meter, etc. were performed. All of the needed calibration reference standards and standard materials were available near each piece of equipment. However, the frequency of calibration and the actual calibration could not be verified because, in most cases, the information was not recorded either on the bench sheet or in an equipment calibration notebook.

5.4 Data Review

The documentation submitted by CIGMAT for the working properties, physical and mechanical properties, and durability properties support the findings as described in this report. The documentation provided by CIGMAT for the TOC analyses showed that the laboratory did not produce sufficient QC documentation to provide traceability to back up the TOC analytical results. Records to support the calibration of the TOC instrument were lacking, such as records of the standards preparation and use of a second source standard to verify calibration of the instrument. Matrix spikes and sample duplicates were not completed for the TOC analyses, and a standard (to verify there was no instrument drift during the analyses) was not run during and at the end of the specimen exposure sample analysis runs. The tap water analysis, which was performed for only one of the two days where TOC analyses were completed, showed an unusually high TOC concentration (10 times typical tap water), which raised questions of whether there was sample contamination or an error in the analysis. Documentation to make this determination was not available. Overall, the TOC data does not have the QA/QC support to validate or refute the reported values.

Section 6
Suggested Reading

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Appendix A
Characterization of Grout

Number of Grout Specimens Tested = 15

The grout material evaluated in this verification program was AV-118 Acrylic Chemical Grout, which is described on the Avanti International Inc. Web site (http://www.avantigrout.com/118sum.html). When a catalyst is added to the water solution of acrylic resins, a gel is formed. AV-118 grout can be used for sealing leaks in sewer pipe joints and can also be used to control water seepage in soil, rocks, or cracks and joints in underground concrete structures. AV-101 Catalyst T+ was used as a buffer chemical and acts as a catalyst, functioning as an activator to the reaction. The primary ingredient in AV-101 Catalyst T+ is triethanolamine. AV-103 catalyst (sodium persulfate – SP) is used as the initiator. The catalyst is an oxidizing agent that triggers the polymerization reaction.

A.1 Preparation of Grout Specimens

As shown in ***Figure A-1***, AV-118 Duriflex Grout was prepared by mixing equal volume of AV-118 resin solution (solution A) with the catalyst solution (solution B).

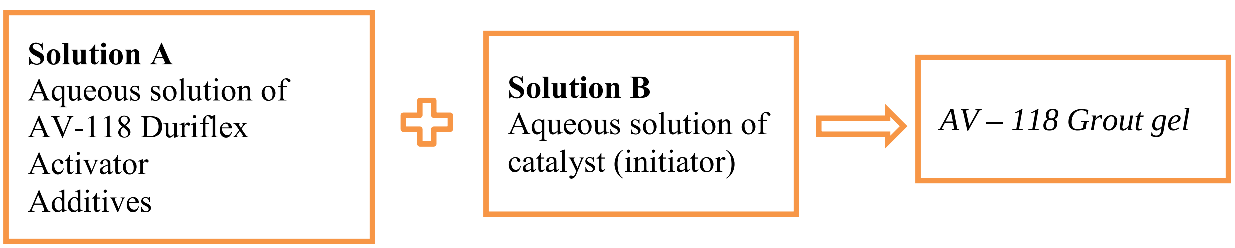

Figure A-1. Procedure for Mixing the Grout Solutions

The two solutions were supplied by Avanti International Inc. to CIGMAT Laboratories for testing and evaluation. Grout specimens were prepared by CIGMAT staff using cylindrical molds (see ***Figure 3-1*** of main document).

The grout specimens were tested for their working properties, physical properties, and leaching characteristics. The working properties included testing the viscosity and gelling time of the grout. The leaching test included the measurement of total organic carbon (TOC) content in the water. The number of specimens used in each test is summarized in ***Table A-1***.

Table A-1. List of Tests Performed on Grout Specimens

Properties	Tests	No. of Specimens Tested
Working Properties	Viscosity	3
	Setting time	6
Physical and mechanical properties	Unit weight	3
Environmental properties	TOC test	3
Total Number of Grout Tests		15

A.2 Test Results

A.2.1 Viscosity

The grout viscosity was evaluated using the procedure outlined in CIGMAT GR 6-04. A cylindrical, spindle-type viscometer (Brookfield Dial-gage Viscometer) was used to test the viscosity of the grout (***Figure A-2***). This instrument was an LV Viscometer that had a spring Torque of 762.7 dyne-cm.

Figure A-2. Brookfield LVT Viscometer

Three samples were tested for viscosity. The tests were performed at three speeds (12, 30 and 60 rpm), and the results are summarized in ***Table A-2***.

Table A-2. Viscosity of AV-118 Chemical Grout

Spindle	Speed	Sample 1		Sample 2		Sample 3	
		Reading	Viscosity	Reading	Viscosity	Reading	Viscosity
Units	rpm		cP				cP
1	60	6.00	6.00	6.00	6.00	5.75	5.75
1	30	2.40	4.80	2.25	4.50	2.40	4.80
1	12	1.00	5.00	1.00	5.00	1.00	5.00
Average Viscosity			5.27		5.17		5.18
			Average Viscosity (cP) = **5.21**				

A.2.2 Setting (Gelling) Time

The setting (gelling) time for the grout mix was evaluated as outlined in CIGMAT standard GR 8-09. Gelling time is defined as the time taken by the grout mix to transform itself from liquid state to solid state from the time of mixing. The gelling time testing was performed at room temperature and room humidity. In total, 6 samples (approximately 100 mL) of grout were prepared and tested, and the results are summarized in ***Table A-3***.

Table A-3. Gelling Time of the Samples

Sample #	1	2	3	4	5	6	Mean
Gelling time (sec)	25	23	23	25	30	21	**24.5**
Standard Deviation: (sec)		**2.81**	Coefficient of Variance (COV):			**0.12**	

The gelling time varied from 21 to 30 seconds, with an average gelling time of 24.5 seconds, a standard deviation of 2.8 sec, and a coefficient of variance (COV) of 0.12.

A.2.3 Unit Weight

The diameter and height of each specimen were measured, and the results are summarized in ***Table A-4***. A total of three specimens were tested.

Table A-4. Summary of Unit Weight for Grout

Specimen #	Weight (g)	Length (mm)	Diameter (mm)	Volume (cm^3)	Density (g/cm^3)	Density (pcf)
1	95.7	81.25	37.01	87.40	1.09	68.3
2	95.3	81.05	36.65	85.51	1.11	69.5
3	86.3	74.37	37.08	80.33	1.07	67.0
Average					1.09	68.3

Based on 3 specimens, the unit weight of grout varied from 1.07 to 1.11 g/cm^3, with an average of 1.09 g/cm^3.

A.2.4 Environmental Test/Leaching Test

Three solidified grout specimens were placed in equal volume of water, and the leachate was analyzed to determine the TOC. The grout (approximately 50 mL) samples were placed in the water for 7 days before the sampling and testing. Also, a blank water sample was used as a control. The test results are summarized in ***Table A-5***. These data should be considered estimated values because of data uncertainty arising from incomplete QA/QC, as discussed in Section 5.4.

Table A-5. Summary of TOC in the Water

Specimen #	Description	Wt. (g)	Volume of Grout (mL)	Volume of Tap water (mL)	Measured TOC (mg/L)	Dilution Factor (mg/l)	corrected TOC (g/L)	TOC (g/L/g grout)
1	7 day old Tap water		-	100	0.026	1x	0.01	
2	AV-118	54.2	50	50	5.884	100x	5.500	0.101
3	AV-118	55.5	50	50	5.686	1000x	5.346	0.096
4	AV-118	54.5	50	50	5.692	1000x	5.350	0.098
Average								0.098

Based on 3 specimens, the TOC in the water varied from 0.096 to 0.101 g/L/g of grout, with an average of 0.098 g/L/g of grout.

Appendix B
Characterization of Grouted Sand

Number of Grouted Sand Tests = 33

In characterizing the grouted sand behavior, a total of 7 different tests were performed using 33 grouted sand specimens over a period of 180 days.

B.1 Unit Weight

A total of 3 specimens were tested. The diameter and height of each specimen was measured at three locations for each specimen, and the results are summarized in ***Table B-1***.

Table B-1. Unit Weight of Grouted Sand

Specimen #	Weight (g)	Length (mm)	Diameter (mm)	Volume (cm^3)	Density (g/cm^3)	Density (pcf)
1	179.4	78.99	38.10	90.06	1.99	124.3
2	226.2	104.39	36.32	108.17	2.09	130.5
3	211.8	91.95	38.10	104.83	2.02	126.1
				Mean	**2.03**	

Based on 3 specimens, the unit weight of grout varied from 1.99 to 2.09 g/cm^3, with an average value of 2.03 g/cm^3.

B.2 Water Absorption

Water absorption was evaluated for grouted sand specimens, as outlined in the standard operating procedure (SOP) CIGMAT GR 3-00. Three grouted sand specimens were immersed in tap water (initial pH in the range of 7 to 8), and changes in weight and volume (determined by measuring specimen diameter and height) of the specimens were recorded for 1 week. The results are summarized in ***Table B-2***.

Table B-2. Water Absorption Test Results

Sample No: 16 – 1						
day	**Diameter**	**Height**	**Weight**	**Volume**	**Weight Change**	**Volume Change**
	Mm	mm	g	cm^3	%	%
Initial	37.92	99.21	232.2	112.00	0.00	0.00
day 1	38.02	99.34	233.9	112.75	0.73	0.67
day 4	38.15	99.39	234.3	113.56	0.90	1.39
day 5	38.15	99.42	234.4	113.59	0.95	1.42
day 6	38.15	99.44	234.4	113.62	0.95	1.44
day 7	38.18	99.62	234.4	113.97	0.95	1.76
Sample No: 17 – 2						
day	**Diameter**	**Height**	**Weight**	**Volume**	**Weight change**	**Volume change**
	mm	mm	g	cm^3	%	%
Initial	38.02	100.89	235.20	114.50	0.00	0.00
day 1	38.02	100.91	237.40	114.53	0.94	0.03
day 4	38.07	100.97	238.00	114.90	1.19	0.35
day 5	38.15	101.02	238.10	115.42	1.23	0.80
day 6	38.18	101.02	238.10	115.57	1.23	0.93
day 7	38.23	101.09	238.10	115.96	1.23	1.28
Sample No: 18 – 3						
day	**Diameter**	**Height**	**Weight**	**Volume**	**Weight change**	**Volume change**
	mm	mm	g	cm^3	%	%
Initial	36.68	100.63	219.50	106.27	0.00	0.00
day 1	36.70	100.58	221.50	106.37	0.91	0.09
day 4	36.75	100.63	221.90	106.71	1.09	0.42
day 5	36.78	100.71	222.00	106.94	1.14	0.63
day 6	36.78	100.76	222.00	107.00	1.14	0.68
day 7	36.78	100.76	222.10	107.00	1.19	0.68

After 1 week of testing, the maximum weight gain varied from 0.95 to 1.23%, with an average of 1.12%. The measured maximum volume change varied from 0.68 to 1.76%, with an average of 1.24%.

Summary – Water Absorption: Based on three specimens, the average percentage weight and volume changes in the AV-118 grouted sand were 1.12% and 1.24%, respectively.

B.3 Shrinkage

Three grouted sand specimens were placed in zip lock bags and kept at room temperature. The testing conditions selected for this study are summarized in ***Table 3-3*** of the main document.

Humidity was measured using a digital humidity meter. The weight and dimensions of the specimens were measured after 28 days and are summarized in ***Table B-3***.

Based on the test results from 3 specimens, the weight loss varied from 0.04 to 0.05%, with an average weight loss was 0.04%. The volume change measured for the three specimens varied from -0. 20 to -1.04 %, with an average volume reduction of -0.61%.

Table B-3. Summary of Shrinkage Test Results

S.No	Time	Temp	Humidity	Weight	Diameter	Height	Volume	Vol. Change	Wt. Change
	days	°C	%	g	mm	mm	cm^3	%	%
4 (1)	1	22	89	236.9	38.20	100.91	115.61		
	28	22.8	92	236.8	38.00	100.94	114.41	-1.04	-0.04
5 (2)	1	22	89	233.0	37.90	101.07	113.94		
	28	22.8	92	232.9	37.90	100.86	113.71	-0.20	-0.04
6 (3)	1	22	89	221.6	36.80	102.54	109.04		
	28	22.8	92	221.5	36.70	102.49	108.38	-0.60	-0.05
Average								-0.61	-0.04

Summary – Shrinkage: Based on the test result from three specimens, the average weight loss was 0.04%, and the average volume reduction was -0.61%.

B.4 Permeability

Three grouted sand specimens were used to determine the permeability. Specimens were prepared in Plexiglas/glass cylinders and permeated with water under a hydraulic gradient of 100, as specified in CIGMAT GR 7-02. Tests were performed at room temperature and humidity.

Table B-4 summarizes the permeability test result. The permeability of the grouted sand was zero; hence, it was characterized as impermeable.

Table B-4. Permeability of Grouted Sand

	Effluent (mL)	Permeability (cm/s)
Specimen 1	0	0
Specimen 2	0	0
Specimen 3	0	0
Average	0	0

Summary – Permeability: Based on the 3 test results, the permeability of the grouted sand was zero under the testing conditions adopted in this study.

B.5 Unconfined Compression

Unconfined compression tests were performed according to CIGMAT GR 2-02. The compression tests were performed using a screw-type machine with capacity of 5,000 lbs. (2,267 kg.) The specimens were loaded at a strain rate of 1%/min. The grouted sand specimens were approximately 1.5 in. (38 mm) in diameter and 2.6 to 3.5 in. (65 to 90 mm) in height. The specimens were trimmed and capped (using a sulfur compound commonly used for capping cement concrete) to ensure smooth and parallel surfaces.

The specimens were tested in triplicate after 3, 7, and 28 days of curing. The test results are summarized in ***Table B-5***. The modulus was determined from the initial slope of the stress/strain curve, and the failure strain is the maximum loading point before the specimen failed.

Table B-5. Compressive Strength Properties

Sample	**Time**	**Stress**	**Strain**	**Modulus**
#	day	psi / kg/cm^2	%	psi / kg/cm^2
1	3	23.1/1.62	4.8	667/46.8
2	3	21.8/1.53	7.1	500/35.1
3	3	35.1/2.47	3.4	1,500/105.4
Average	**3**	**26.7/1.88**	**5.1**	**888/62.4**
1	7	22.0/1.55	5.4	556/39.0
2	7	17.0/1.19	9.4	286/20.1
3	7	23.5/1.65	4.7	667/46.8
Average	**7**	**20.8/1.46**	**6.5**	**502/35.2**
1	28	25.7/1.80	2.9	929/65.3
2	28	32.3/2.27	3.8	1,250/87.8
3	28	31.3/2.20	4.1	1,000/70.3
Average	**28**	**29.8/2.09**	**3.6**	**1,060/74.5**

Based on the test results, the compressive strength and modulus increased with curing time. The failure strain decreased with curing time. The average compressive strength after 3 days of curing was 26.7 psi (1.88 kg/cm^2), and it increased to 29.8 psi (2.09 kg/cm^2) after 28 days of curing time. The average compressive modulus after 3 days of curing was 888 psi (62.4 kg/cm^2), and it increased to 1,060 psi (74.5 kg/cm^2) after 28 days of curing time.

Summary – Unconfined Compression: Based on the test results, the average compressive strength of grouted sand after 3 days of curing was 26.7 psi (1.88 kg/cm^2), and it increased to 29.8 psi (2.09 kg/cm^2) after 28 days of curing time. The average compressive modulus of grouted sand after 3 days of curing was 888 psi (62.4 kg/cm^2), and it increased to 1,060 psi (74.5 kg/cm^2) after 28 days of curing time.

B.6 Wet-Dry Cycles

A total of 3 specimens were tested for 10 cycles. The cycles started with a wet cycle. The changes in weight, length, diameter, and volume are summarized in ***Table B-6***. After the first wet-dry cycle, the average changes in weight, length, diameter, and volume were 0.69%, 0.08%, 0.20%, and 0.33%, respectively. After the tenth wet-dry cycle, the average changes in weight, length, diameter, and volume were 0.05%, 0.33%, -0.21%, and 0.09%, respectively. The average unit weight of the specimens remained the same after 10 cycles. The average strength of the grout after 10 wet-dry cycles was 29.1 psi. (2.04 kg/cm^2)Hence, the specimen strength was not affected after 10 wet-dry cycles.

Table B-6. Wet-Dry Cycle Test Results

	Specimen #	Weight (g)	Length (mm)	Diameter (mm)	Volume (cm^3)	Density (g/cm^3)
Original	1	235.2	100.91	38.02	114.56	2.05
	2	232.2	99.21	37.92	112.05	2.07
	3	219.5	100.58	36.68	106.27	2.07
	Average					2.06

	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
Cycle 1	1	0.765	0.071	-0.277	0.483	2.06
	2	0.517	0.154	-0.402	0.651	2.07
	3	0.774	0.000	0.069	-0.138	2.08
	Average	0.69	0.08	0.20	0.33	2.07

	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
Cycle 2	1	0.85	0.323	-0.344	0.364	2.06
	2	0.560	0.410	-0.201	-0.009	2.08
	3	0.774	0.000	-0.069	0.139	2.08
	Average	0.73	0.24	-0.21	0.17	2.07

	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
Cycle 3	1	0.723	0.323	-0.210	0.097	2.07
	2	0.517	-0.102	-0.335	0.774	2.07
	3	0.820	0.000	0.277	-0.553	2.09
	Average	0.69	-0.07	0.089	0.11	2.08

Cycle 4	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
	1	0.808	0.323	-0.144	-0.037	2.07
	2	0.646	0.922	-0.603	0.276	2.08
	3	0.866	0.505	0.208	-0.918	2.10
	Average	0.77	-0.58	-0.18	-0.23	2.08

Cycle 5	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
	1	0.680	0.071	-0.344	0.617	2.05
	2	0.560	0.154	-0.469	0.785	2.07
	3	0.774	0.00	-0.069	0.139	2.08
	Average	0.67	0.08	-0.29	0.51	2.07

Cycle 6	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
	1	0.595	0.323	-0.277	0.230	2.06
	2	0.431	-0.102	-0.201	0.505	2.07
	3	0.592	0.253	0.139	-0.529	2.09
	Average	0.54	0.16	-0.21	0.07	2.07

Cycle 7	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
	1	0.553	0.575	-0.344	0.111	2.06
	2	0.474	0.666	-0.134	-0.399	2.09
	3	0.683	0.000	0.253	-0.277	2.09
	Average	0.57	-0.41	-0.08	-0.19	2.08

Cycle 8	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
	1	0.638	0.071	-0.411	0.751	2.05
	2	0.431	0.666	0.410	0.268	2.08
	3	0.866	0.000	-0.139	-0.253	2.09
	Average	0.65	0.25	-0.04	0.26	2.07

Cycle 9	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
	1	0.000	0.499	-0.077	-0.346	2.06
	2	-0.043	0.410	0.000	-0.410	2.08
	3	0.182	0.505	-0.139	-0.229	2.07
	Average	0.05	0.47	-0.07	-0.33	2.07

Cycle 10	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
	1	-0.043	0.575	-0.478	0.377	2.04
	2	-0.086	-0.102	0.067	-0.032	2.07
	3	0.273	0.505	-0.208	-0.091	2.07
	Average	0.05	0.33	-0.21	0.09	2.06

Table B-7. Compressive Strength after wet-dry cycles

Sample	**time**	**Strain**	**Stress**	**Modulus**
#	days	%	psi / kg/cm^2	psi / kg/cm^2
1	140	3.82	31.7/2.22	953/67
2	140	5.64	26.9/1.89	733/51.5
3	140	4.43	28.9/2.03	725/50.9
average		**4.63**	**29.2/2.05**	**803/56.4**

Summary – Wet-Dry Cycles: After 10 wet-dry cycles, the average changes in weight, length, diameter, and volume were 0.05%, 0.33%, -0.21%, and 0.09%, respectively. The average unit weight of the specimens remained the same after 10 cycles. The average strength of the grout after 10 wet-dry cycles was 29.1 psi (2.04 kg/cm^2); hence, the specimen strength was not affected after 10 wet-dry cycles.

B.7 Chemical Resistance

A total of 9 specimens were tested for a period of 6 months. A total of 3 specimens were tested in pH=2, 7, and 10 solutions, respectively. The test results are summarized in ***Table B-8***.

pH= 2 solution: After 1 month, the average changes in weight, volume, and unit weight were 1.98%, 0.92%, and 0.98%, respectively After 6 months, the average changes in weight, volume, and unit weight were 2.49%, 1.50%, and 0.98%, respectively. The weight and volume increased over period of 6 months. The average compressive strength was 18.2 psi (1.27 kg/cm^2), (see ***Table B-9***).

pH= 7 -water: After 1 month, the average changes in weight, volume, and unit weight were 1.84%,1.25%, and 0.98%, respectively After 6 months, the average changes in weight, volume, and unit weight were 1.84%, 1.73%, and 0.49%, respectively. The change in weight was negligible, and volume increased over period of 6 months. The average compressive strength was 17.5 psi (1.23 kg/cm^2), (see ***Table B-9***).

<u>pH= 10 solution</u>: After 1 month, the average changes in weight, volume, and unit weight were 1.67%, 1.45%, and 0.00%, respectively After 6 months, the average changes in weight, volume, and unit weight were 1.67%, 1.21%, and 0.49%, respectively. The average compressive strength was 21.3 psi (1.49 kg/cm^2), (see ***Table B-9***).

Table B-8. Summary of Chemical Resistance Test Results

Specimen #		Weight (g)	Length (mm)	Diameter (mm)	Volume (cm^3)	Density (g/cm^3)
Original (pH=2)	1	231.0	100.55	37.90	113.41	2.04
	2	240.9	103.79	37.99	117.64	2.05
	3	178.9	77.89	37.97	88.21	2.03
	Average	216.9	94.08	37.95	106.42	2.04
30 days (pH=2)	1	234.7	100.83	38.01	114.38	2.05
	2	244.9	104.69	37.96	118.49	2.07
	3	184.0	78.50	38.06	89.32	2.06
	Average	221.2	94.67	38.01	107.40	2.06
	% Change	1.98	0.63	0.16	0.92	0.98
3 months (pH=2)	1	236.2	100.66	38.13	114.91	2.06
	2	247.2	105.02	37.94	118.71	2.08
	3	184.5	78.24	38.07	89.08	2.07
	Average	222.6	94.64	38.05	107.57	2.07
	% Change	2.63	0.60	0.26	1.08	1.47
6 months (pH=2)	1	236.2	100.97	38.04	114.72	2.06
	2	246.8	105.00	38.00	119.07	2.07
	3	183.8	78.82	38.19	90.27	2.04
	Average	222.3	94.93	38.08	108.02	2.06
	% Change	2.49	0.90	0.34	1.50	0.98

Specimen #		Weight (g)	Length (mm)	Diameter (mm)	Volume (cm^3)	Density (g/cm^3)
Original (pH=7)	1	231.1	100.74	38.02	114.39	2.02
	2	237.2	101.85	37.91	114.98	2.06
	3	214.7	100.03	36.63	105.39	2.04
	Average	227.7	100.87	37.52	111.59	2.04
30 days (pH=7)	1	235.9	100.92	38.04	114.69	2.06
	2	241.3	102.13	38.25	117.37	2.06
	3	218.6	100.51	36.75	106.63	2.05
	Average	231.9	101.19	37.68	112.90	2.06
	% Change	1.84	0.32	0.43	1.17	0.98
3 months (pH=7)	1	237.0	100.63	38.07	114.58	2.07
	2	241.3	102.29	38.18	117.08	2.06
	3	218.6	101.07	36.68	106.78	2.05
	Average	232.3	101.33	37.64	113.81	2.06
	% Change	2.02	0.46	0.32	1.99	0.98
6 months (pH=7)	1	236.3	102.34	38.10	116.67	2.03
	2	240.5	102.37	38.23	117.49	2.05
	3	218.8	100.22	36.73	106.17	2.06
	Average	231.9	101.64	37.69	113.44	2.05
	% Change	1.84	0.76	0.45	1.66	0.49
Original (pH=10)	1	232.7	100.13	37.92	113.09	2.06
	2	233.3	100.60	37.91	113.56	2.05
	3	235.1	101.18	37.92	114.28	2.06
	Average	233.7	100.64	37.92	113.64	2.06

Specimen #		Weight (g)	Length (mm)	Diameter (mm)	Volume (cm^3)	Density (g/cm^3)
30 Days (pH=10)	1	236.2	100.87	38.10	115.00	2.05
	2	237.9	100.89	38.05	114.71	2.07
	3	238.6	101.88	38.10	116.15	2.05
	Average	237.6	101.21	38.08	115.29	2.06
	% Change	1.67	0.57	0.42	1.45	0.00
3 months (pH=10)	1	236.3	100.76	37.96	114.03	2.07
	2	238.1	101.00	38.02	114.69	2.08
	3	238.6	101.65	37.89	114.59	2.08
	Average	237.7	101.14	37.96	114.44	2.08
	% Change	1.71	0.50	0.11	0.70	0.97
6 months (pH=10)	1	236.2	100.55	38.07	114.48	2.06
	2	237.9	100.55	38.27	115.62	2.06
	3	238.6	100.57	38.15	114.96	2.08
	Average	237.6	100.56	38.16	115.01	2.07
	% Change	1.67	-0.08	0.63	1.21	0.49

Table B-9. Compressive Properties after Chemical Resistance Test

Sample	pH	Stress	Strain	Modulus
#		psi / kg/cm^2	%	psi / kg/cm^2
1	2	19.9/1.39	6.64	516/36.2
2	2	20.5/1.44	6.63	361/25.3
3	2	17.6/1.23	6.87	374/26.2
Average		**19.3/1.35**	**6.46**	**417/29.3**
1	7	14.4/1.01	5.89	313/22.0
2	7	23.0/1.61	5.13	530/37.2
3	7	15.8/1.11	4.94	421/29.5
Average		**17.7/1.24**	**5.32**	**421/29.5**
1	10	22.2/1.56	4.53	749/52.6
2	10	20.4/1.43	5.38	506/35.5
3	10	21.2/1.49	4.73	471/33.1
Average		**21.3/1.49**	**4.88**	**575/40.4**

Summary – Chemical Resistance: After 6 months in a pH =2 solution (acid), the average changes in unit weight and volume in the grouted sand were 0.98% and 1.50%, respectively. After 6 months in a pH =7 solution (neutral), the average changes in unit weight and volume in the grouted sand were 0.49% and 1.73%, respectively. After 6 months in a pH =10 solution (base), the average changes in unit weight and volume were 0.49% and 1.21%, respectively. The average compressive strengths of grouted sand in acidic, neutral, and basic environments were 19.3, 17.7 and 21.3 psi (1.35, 1.24 and 1.49 kg/cm^2), respectively.

Appendix C
Grout Vendor Data Sheets

GROUT VENDOR DATA SHEET

Grout Product Name: AV-118 Duriflex

Grout Product Manufacturer Name and Address: Avanti International

822 Bay Star Blvd., Webster, TX 77598

Grout Type: Acrylic Chemical Grout –AV-118 Duriflex

Chemical Formula: Confidential Business Information

TESTING METHOD	MANUFACTURER'S RESULTS
Type of Resin, Initiator and/or Promotor	Acrylic Gel + Cat-T (Initiator) + Sodium Persulfate (Oxidizer) + AV-105 + AV-257
Grout Mix (by weigh or volume)	25% by volume
Resin Viscosity (ASTM __________)	1.2 cps of grout mix
Flash Point (ASTM D 93/ __________)	> 200 degrees F
Tensile Adhesion to Concrete and Clay Brick (ASTM ________)	N/A
Chemical Resistance (ASTM __________) (NaOH, 3% H_2SO_4 or others)	NaOH = Good; H_2SO_4 = Poor; avantigrout.com/118tech.html
Volatile Organic Compounds – VOCs (ASTM _____________)	None

WORKER SAFETY	RESULT/REQUIREMENT
Flammability Rating	Not determined
Known Carcinogenic Content	Listed as potential carcinogen
Other Hazards (Corrosive)	None
MSDS Sheet Availability	Online, email, regular mail

ENVIRONMENTAL CHARACTERISTICS	RESULT/REQUIREMENT
Heavy Metal Content (w/w)	None
Leaching from Cured Grouts	None
Disposal of Cured Grouts	Non-toxic, inert, irreversible. In accordance with local, state and federal regulations. Usually may be thrown away.

DATA SHEET ON PROPERTIES OF GROUT (Continued)

APPLICATION CHARACTERISTICS	RESULT/REQUIREMENTS
Minimum Application Temperature	None
Maximum Application Temperature	Not determined
Minimum Cure Time before Immersion into Service	N/A
Type of Preparation Before Grouting	See mixing instructions
Grouting Pressure	< 50 psi

VENDOR EXPERIENCE	COMMENTS
Length of Time the Grout in Use	20 years
Applicator Training and Qualification Program	Avanti's Safe Operating Practices Program
QA/QC Program for Grouts in the Field	See attached mixing instructions. Working on developing a grout-content field test.

ADDITIONAL COMMENTS (Including Case Studies on Performance)

(1) 38-ft. Lateral Sealing in Wisconsin Provides Opportunity for Innovation

(2) Toronto Successfully Using Acrylamide Grout to Stop Tunnel Leaks

(3) Lateral Packers and Grout Close in on Infiltration