

Environmental Technology Verification Report Grouts for Wastewater Collection Systems

Warren Environmental, Inc.
301-04 Epoxy GROUT

Prepared by



Center for Innovative Grouting Materials and Technology
University of Houston

RTI International & NSF International

Prepared for:

 U.S. Environmental Protection Agency

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Environmental Technology Verification Report

Verification of Grouts for Rehabilitation of Wastewater Collection Systems

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2012

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 (TO) 61, Field Verification of Drinking Water and Wastewater Systems Assessment and Rehabilitation Technologies, of Contract No. EP-C-05-060, with RTI International. The testing was performed by the Center for Innovative Grouting Materials and Technology (CIGMAT); NSF International 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
°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
kg/m ³	Kilogram(s) per cubic meter
L	Liter
lbs	Pounds
min	Minute(s)
NRMRL	National Risk Management Research Laboratory
m/sec	Meter(s) per second
m ³	Cubic meters
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
RPD	Relative Percent Difference
Room conditions	Temperature of 23°C ±2°C 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 infiltration of leaking water from the surrounding environments. Rehabilitation of these facilities by in situ methods, including the 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 grout used for repairs must be durable enough to withstand the effect of the severe physical and chemical environmental conditions to which it will be subjected to during the service life.

This verification evaluated Warren Environmental 301-04 grouting material 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 performance under various simulated physical and chemical environments. Grout was characterized based on setting time, unit weight, and leaching of organics in water by performing a series of tests. The grout behavior was characterized based on the unit weight, water absorption, shrinkage, permeability, compressive strength, wet-dry cycle, and chemical resistance tests. The compressive strength of grout was determined for a period up to a month of curing time. Also, the changes in length, diameter, volume, and weight of the grouted sand were studied in up to 10 wet-dry cycles. Finally, two model tests were performed to determine the effectiveness of grouting in reducing the leakage at the joints.

Testing resulted in the following observations for Warren Environmental's 301-04 grout:

- Model tests showed that grouting with 301-04 significantly reduced or eliminated the leak in a simulated one-inch open joint (0 to 19.3 gallons/87.7 liters/day water leaks at 5 psi/0.35 kg/cm² water pressure) immediately after grouting, and after two wet and dry cycles over period of 1 month (0 to 16.2 gallons/73.6 liters/day water leaks at 5 psi/0.35 kg/cm² water pressure). Prior to grouting all of the water leaked out of the open pipe joint.
- The setting time of the grout at room temperature (70°F/21°C) varied from 38 to 40 minutes. The average unit weight of the solid grout was 62.6 pcf (1.00g/cm³). The average total organic content (TOC) in the leaching water was 0.0017 g/L/g of grout.
- During the water absorption test (under saturated conditions), the weight change in the specimens varied from 0.09% to 0.17%, with an average of 0.14%. The volume change in the specimen varied from 0.03% to 0.05%, with a mean of 0.04%.
- The shrinkage at 90% humidity and 23°C temperature after 28 days of testing resulted in an average weight and volume change of 0.03% and 0.01%, respectively.
- The grout was impermeable under a hydraulic gradient of 100.
- The average strength, failure strain, and initial modulus after 3 days of curing were 6,591 psi (463 kg/cm²), 9%, and 225,000 psi (1,5819 kg/cm²), respectively. The average

strength, failure strain, and initial modulus after 28 days of curing were 6,180 psi (434 kg/cm²), 5%, and 195,000 psi (13,709 kg/cm²), respectively.

- After the tenth wet-dry cycle, the average change in weight, length, diameter, and volume was 0.25%, -0.41%, 0%, and -0.41%, respectively. The unit weight of the specimens increased by 0.99%. The average strength of the grout after 10 wet-dry cycles was 6,531 psi (459 kg/cm²); hence, the specimen strength was not affected after 10 wet-dry cycles.
- After 6 months in a pH =2 solution (acid), the average change in unit weight and volume was -0.31% and 1.70%, respectively. After 6 months in a pH =7 solution (neutral tap water), the average change in unit weight and volume was 0.77% and 0.47%, respectively. After 6 months in a pH =10 solution (base), the average change in unit weight and volume was 0.79% and 0.47%, respectively.
- The bonding strength for water cured grout-concrete specimens did not vary significantly over a 6-month exposure period, with average strengths ranging from 257 to 280 psi (18.0 to 19.7 kg/cm²); most of the specimen failures were Type 1 (substrate), with others being Type 4 (substrate failure with the grout intact).
- After 6 months of the grout-substrate test, following 10 wet-dry cycles, the average bonding strength was 233 psi (16.4 kg/cm²), and all (100%) of the failures were Type 1 (see Appendix C for illustrations of failure types).

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), two 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 Warren Environmental 301-04 Epoxy grout was completed following the *Generic Test Plan for Verification of Grouts for Wastewater Collection Systems, 2009* (henceforth referred to as the Generic Test Plan). The Generic Test Plan (GTP) was used to develop a product-specific verification test plan (VTP) for the Warren Environmental 301-04 Epoxy 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)

The Verification Organization (VO) for verifications conducted under this test plan is RTI International (RTI) and NSF. The primary responsibilities of the VO are the following:

- Coordinate with the Center for Innovative Grouting Materials and Technology (CIGMAT), the TO, and the Vendor to prepare and approve a product-specific test plan using the GTP as a template and meeting all testing requirements included herein;
- 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 grout evaluations and associated laboratory testing;
- Review data generated during verification testing;
- Oversee the development of a verification report;
- Provide QA oversight at all stages of the verification process.

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1.2.2 U.S. Environmental Protection Agency (EPA)

This report has been funded and 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 reviewed and approved each phase of the verification project. The primary responsibilities of EPA personnel were the following:

- Review and approve the VTP, including the test/quality assurance plans (T/QAPs);
- Sign the VTP 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 this 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 VTP 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. CIGMAT personnel worked in groups to complete the tests described in the VTP. 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, was responsible for internal audits.

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1.2.4 Vendor (Warren Environmental)

The Vendor for verifications conducted under the VTP is Warren Environmental Inc. The primary responsibilities of the Vendor are the following:

- Provide the TO with pre-grout samples for verification;
- Complete a product data sheet prior to testing;
- 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

The 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) behavior of grout-concrete substrate under various environmental conditions; and (3) model verification of various grout applications. The data collected on various grouts can further 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 rehabilitation of cracked concrete to control leakage. Specific testing objectives are to:

- Evaluate the effectiveness of the grout to control leakage at a simulated cracked concrete structure; and
- Determine the relevant grout 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 of Houston 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 Warren Environmental 301-04 Epoxy grout for use in controlling leaks in cracked concrete. Specific objectives are as follows:

- Determine the working properties of the grout material;
- Determine the physical and mechanical properties of the grout material over a period of time and exposure conditions;
- Evaluate the grout-substrate interaction over a period of 6 months; and

- Determine the effectiveness of the test grout for controlling leaks in cracked concrete over a period of time.

Section 2 Grout Material Description

The grout material evaluated in this verification was the M-301 Epoxy Trowel-On Mastic System Grout from Warren Environmental. The grout is described on the Warren Environmental Inc. Web site (<http://www.warrenenviro.com/pdf/301-04.pdf>) as a two-part, highly thixotropic (becomes fluid when stirred or shaken) epoxy system formulated specifically for trowel-on applications.

Based on the information provided by the supplier, 301-04 Epoxy Grout can be used for sealing leaks in sewer pipe joints, and can also be used to control water seepage in cracks and joints in subgrade concrete structures. The grout was formulated with special additives and modifiers to enhance water and chemical resistance, and bond strength to a variety of substrates, as well as its own internal strength. The high thixotropic index allows for build-ups of up to $\frac{3}{4}$ in. on vertical surfaces without sag. It has been designed to be applied to a clean surface free of standing water with a notched (toothed) trowel similar to stucco. Alternately, it may be applied using heated tanks, heated lines, and Warren Environmental Inc.'s patented meter, mix, and spray equipment. This epoxy system utilizes a 2 parts base-to-1 part activator mix ratio by volume. This product is sold and installed only by technicians specifically trained and licensed in the manufacturer's patented techniques.

The cured 301-04 epoxy grout is white in color, as shown in **Figure 2-1**.



Figure 2-1. 301-04 Epoxy grout specimen.

Section 3

Methods and Test Procedures

The testing involved characterization of grout material and bonding strength to concrete. 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 there were no American Society of Testing and Materials (ASTM) test procedures to determine the grout properties, CIGMAT developed their own testing protocols, which were used in these evaluations.

3.1.1 Grout Specimen Preparation

3.1.1.1 Grout Specimens

Figure 3-1 shows the mold utilized to make the grout test specimens. Specimens were prepared with a resin-to-water ratio of 9:1. Specimens were cured under room conditions. 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 $23 \pm 2^\circ\text{C}$ (room temperature) and $50\% \pm 5\%$ humidity.

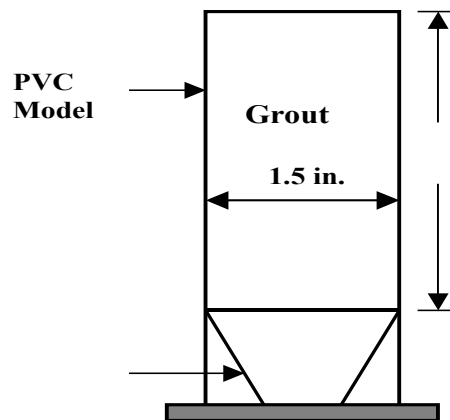


Figure 3-1. Typical mold used for preparing grout specimens.

Table 3-1. Grout Tests for Concrete Leak Repair

Properties	Tests	Conditions	Test Method Used	# of Specimens Tested
Working Properties	Setting (Gel) Time	23°C	Method defined in Section 3.1.2.	6
Physical and Mechanical Properties	Unit Weight	23°C	CIGMAT GR 1-04	25
	Water Absorption	23°C	CIGMAT GR 3-04	3
	Shrinkage	Temp, humidity	Method defined in Section 3.1.2	3
	Permeability	Water	CIGMAT GR 7-04	3
	Compressive Strength	3, 7, 28 days	CIGMAT GR 2-04	11
Durability Properties	Wet-Dry Cycle	Number of cycles	CIGMAT GR 3-04	3
	Chemical Resistance	pH = 2, 7, 10	CIGMAT CH 2-04	9
Environmental Properties	Leaching	Water	Method defined in Section 3.1.2	3

Table 3-2. Grout-Substrate Interaction Tests

Materials	Tests	Conditions	Test Method Used	Number of Specimens Tested
Grout-Substrate Interaction				
Bonding Strength	Wet condition	Concrete brick cured under water	CIGMAT CT 3-00	12
	Wet-dry cycle	Number of cycles	CIGMAT GR 3-04 & CIGMAT CT 3-00	3

3.1.1.2 Grout-Substrate Interaction Specimens

Although CIGMAT CT 3-00 was developed for coating materials, it can be adopted for grouts. As described in CIGMAT CT 3-00, the grout was sandwiched between a pair of rectangular concrete block specimens and then tested for bonding strength and type of failure. Even though CIGMAT CT 3-00 specifies the use of dry bricks, for the purposes of this grout evaluation, wet specimens were used to simulate extreme grouting conditions. The bonded wet specimens were immersed in water until tested. The reported data include the number of specimens tested; the

age of specimen at the time of the test; the average bond strength with standard deviation; and the types of failures.

3.1.2 Grout Curing Properties

3.1.2.1 *Setting (Gel) Time*

No ASTM standard method is currently available to determine the gel time for epoxy grouts. Hence, it was determined by the elapsed time from grout preparation until the grout no longer flowed from a plastic cup or beaker inclined slowly (so that if the cup/beaker were filled with liquid, the surface of the liquid would remain level) to 45 degrees. 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.

3.1.2.2 *Physical and Mechanical Properties*

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

3.1.2.3 *Unit Weight (Density)*

Solidified grout specimens were used to determine the unit weight of the grout. The determinations were completed per CIGMAT GR 1-00 for grout specimens. Unit weights were calculated using the weight and volume of the specimens. Three replicates were evaluated for unit weight.

3.1.2.4 *Water Absorption*

Water absorption characteristics were evaluated for grout specimens as outlined in standard procedure CIGMAT GR 3-04. Three grout specimens were immersed in tap water (initial pH in the range of 7), and changes in the weight and volume (determined by measuring specimen diameter and height) of the specimens were recorded a minimum of once every working day (Monday through Friday, excluding holidays) until the changes in weight and volume became negligible (less than 0.5 percent of the previous weight and volume), or for 1 week, whichever occurred first.

3.1.2.5 *Shrinkage*

The specimens were placed in zip lock bags and held at room temperature. Humidity was measured using a digital humidity meter. At the onset of the test, specimens were prepared in a mold with inner dimensions of 1.5 in. (38 mm) in diameter and 3.5 in. (90 mm) in length. 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	23°C ± 2°C for 28 days in zip lock bags (RH = 90% ± 5%)

3.1.2.6 Permeability

Solidified grout specimens were used to determine the grout's permeability. Specimens were prepared in 1.5 in. (33 mm) diameter Plexiglas/glass cylinders and permeated with water under a hydraulic gradient of 100, per CIGMAT GR 7-02. Testing of three replicate samples was completed at room temperature and humidity.

3.1.2.7 Unconfined Compressive Strength and Stress/Strain Relationship

CIGMAT GR 2-02 was developed for testing grout 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 fails.

3.1.3 Durability Properties

3.1.3.1 Wet/Dry Cycle

During its service life, the grout 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. 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 (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% relative humidity [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 grout.

3.1.3.2 Chemical Resistance

This test evaluates the resistance of grouts 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 grout 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 change 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 on the specimens in accordance with Section 7.4 of CIGMAT CH 2-01.

3.1.4 Environmental Properties—Leaching Test

Potential contaminant leaching from solidified grout was determined by analyzing water exposed to the grout for total organic carbon (TOC). Lead is an issue with inorganic grout, but is not an issue with the proposed grout, so no lead evaluation was required. Three test replicates, using cylindrical grout specimens, were exposed to tap water in individual exposure jars for 7 days. 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 and water volume so that there was an adequate volume exposed to water to conduct the required analyses. A liquid-to-solid ratio of 1:1 (by volume) was used.

At the end of the exposure period, samples of the exposure water were analyzed to determine the presence of organic compounds that may have leached out 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 4°C, pH<2 HNO ₃ , 6 months	1 mg/L

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

3.2 Grout-Substrate Bonding Strength

Interaction between the grout and a concrete substrate was evaluated by testing the bonding strength and type of failure (i.e., bonding failure, substrate failure, or a combination) under different service conditions. Testing of wet grout/concrete substrate specimens was conducted over a period of 6 months, in accordance with CIGMAT CT 3-00 (over the grouted area between the concrete bricks/prisms, as selected by the vendor prior to the ETV verification. In addition, bonded configurations prepared according to CIGMAT CT 3-00 were also subjected to wet/dry cycle test.

3.3 Model Test

For this study, Warren Environmental Inc. selected the model test related to leak control in cracked concrete.

3.3.1 Model Test: Concrete Leak Repair

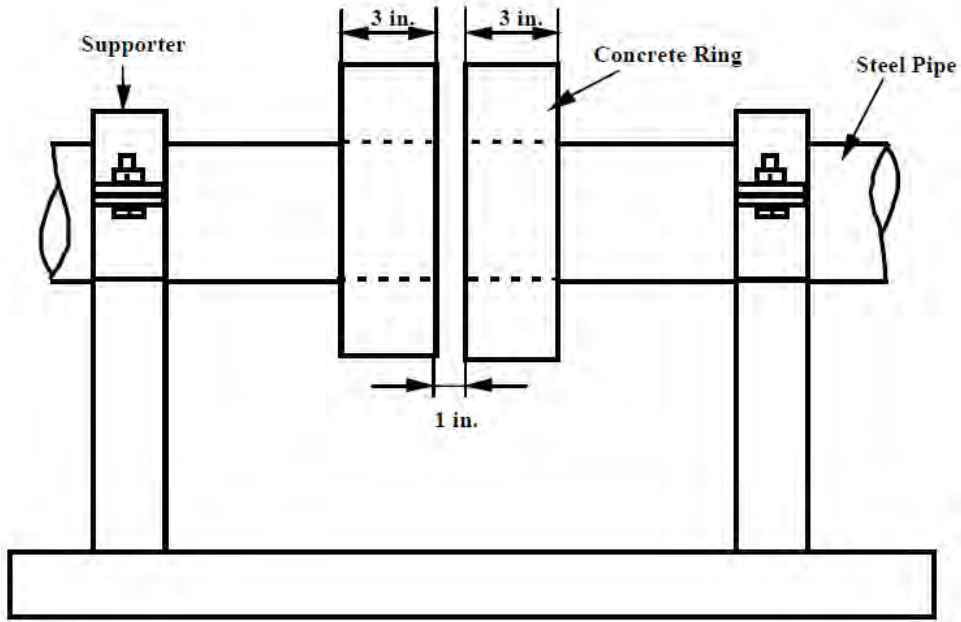
In order to simulate a leak in a concrete structure, this model test (**Figure 3-2**) uses 10 in. (25 cm) diameter circular concrete disks with 6 in. (15 cm) openings at the center (each disk is donut-shaped). The two disks were placed 1 in. apart and the opening was grouted by the vendor. After the vendor-specified curing period, the grouted joint was subjected to hydrostatic pressure testing to determine the leak rate, as outlined in Section 3.3.2.

3.3.2 Model Test Procedures

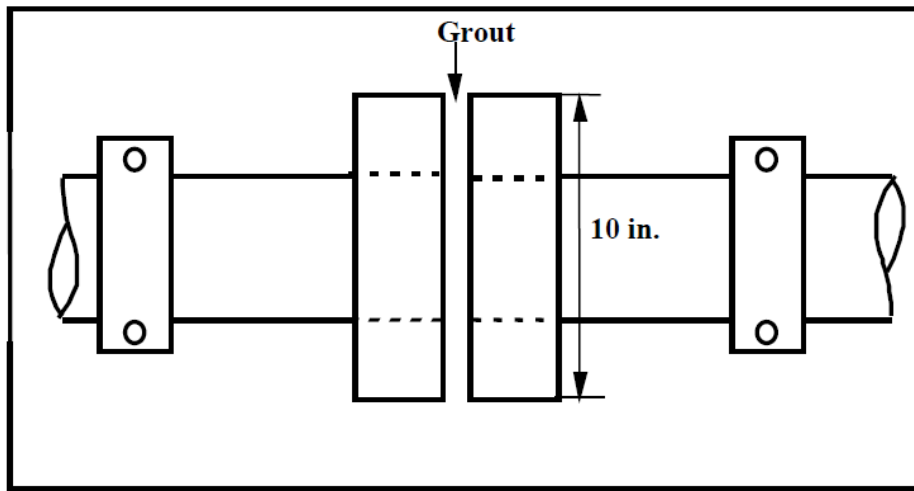
The grouted concrete disks were subjected to the following test procedures:

1. Apply hydrostatic pressure of 3 psi (0.21 kg/cm²) and hold for 5 minutes; then measure the leak rate using a graduated cylinder and a stopwatch.
2. Repeat Step 1 at a hydrostatic pressure of 4 psi (0.28 kg/cm²).
3. Repeat Step 1 at a hydrostatic pressure of 5 psi (0.35 kg/cm²).
4. Maintain saturated conditions for a period of 1 week by soaking the joint with water.
5. Drain all water from the test chambers and allow them to stand for 1 week.
6. Fill the chambers with water and repeat Step 4.
7. Repeat Step 5.
8. Determine leak rates as described in Steps 1 through 3.

The reported data include the characteristic leak rate versus pressure for each grouted joint.



(a) Elevation View



(b) Plan View

Figure 3-2. Model configuration for testing concrete leak repair.

Section 4 Results and Discussion

As previously described in **Section 3**, a series of tests were completed on the Warren Environmental 301-04 Epoxy grout to characterize the material and provide information on how the grout will perform under various conditions of applications. Grout specimens were tested to identify their working properties, physical and mechanical properties, durability properties, and environmental properties. In addition, tests were completed to evaluate the grout/substrate interaction. The results of these tests are presented in this section.

4.1 Grout Properties

4.1.1 Working Properties

The working properties describe the basic characteristics of the grout material and also help with establishing quality control (QC) procedures for various types of field applications.

4.1.1.1 Viscosity

This is a typical descriptive of the flow characteristics of a grout material. However, as the grout was a solid at room temperature, the viscosity test was not performed.

4.1.1.2 Setting (Gel) Time

The setting time testing was performed at room temperature and humidity. A total of six samples were tested, and the results are summarized in **Table 4-1**. Setting time varied from 38 to 40 minutes, with an average of 39 minutes. The setting time will control the installation time for the grout.

4.1.1.3 Unit Weight (Density)

A total of 25 cylindrical specimens were tested, and the results are summarized in **Table B-2** of **Appendix B**. The grout unit weight varied from 0.91 to 1.09 g/cm³, with an average of 1.00 g/cm³, the unit weight of water. The unit weight of the grout could be used as a quality control measure in the field and will also help with the estimation of changes in weight due to the leak repairs.

Table 4-1. Summary of Working Properties of Epoxy Grout

Test Completed	Number of Specimens	Range	Mean	Standard Deviation	CV
Setting Time (min)	6	38–40	39.5	0.84	0.02
Unit Weight (g/cm ³)	25	0.91–1.09	1.00	0.05	0.05

4.2 Physical and Mechanical Properties

4.2.1 Water Absorbance

The water absorption is a representation of the water-diffusion characteristics of the grout. A total of three specimens were tested, and the results are summarized in **Table 4-2**. The weight

change in the three specimens varied from 0.09% to 0.17%, with an average of 0.14%. The volume change in the specimen varied from 0.03% to 0.06%, with a mean of 0.04%.

Table 4-2. Results of Water Absorption

Exposure Time (days)	Specimen 41			Specimen 42			Specimen 43		
	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	0.98			0.98			0.99		
1	0.98	0.08	0.03	0.98	0.17	0.03	0.99	0.09	0.03
2	0.98	0.15	0.03	0.98	0.17	0.03	0.99	0.09	0.06
3	0.98	0.15	0.05	0.98	0.17	0.03	0.99	0.09	0.06
4	0.98	0.15	0.05	0.98	0.17	0.05	0.99	0.09	0.03

4.2.2 Shrinkage Test

A total of three specimens were tested for 28 days. The weight change varied from 0 to 0.09%, with an average value of 0.06%. The volume change varied from 0 to 0.04%, with an average of 0.01%.

4.2.3 Permeability

Grout specimens that were cured for a period of 7 days were tested for permeability under a hydraulic gradient of 100. Three specimens were tested, with no observed discharge from any of the three specimens over the 72 hour test period the gradient was applied. Hence the permeability of the grout was zero. The results of the test are summarized in **Appendix B, Table B-5**.

4.2.4 Compressive Strength and Stress-Strain Relationship

The compressive properties (i.e., strength, failure strain, and initial modulus) were measured over a period of 30 days. A total of 11 specimens were tested, and the results are summarized in **Table 4-3**. The average strength, failure strain, and initial modulus after 3 days of curing were 6,591 psi (463 kg/cm²), 9%, and 225,000 psi (15,819 kg/cm²), respectively. The average strength, failure strain, and initial modulus after 28 days of curing were 6,180 psi (434 kg/cm²), 5%, and 195,000 psi (13,709 kg/cm²), respectively. The complete set of data for this test is included in **Appendix B, Table B-6**.

Table 4-3. Summary of Compressive Strength Properties with Curing Time

Number of Specimens	Cure Time (days)	Compressive Strength (psi)/(kg/cm ²)		Failure Strain (%)		Avg. Initial Modulus (psi)/(kg/cm ²)	
		Average	Range	Average	Range	Average	Range
3	3	6,591 463	6,105 - 7,356 429-517	9	8 – 10	225,000 15,819	200,000- 250,000 14,061-17,576
3	7	6,402 450	5,304 - 7,592 372-533	5	3 – 7	227,000 15,959	215,000 - 240,000 15,116-16,873
5	28	6,180 434	5,451- 7,022 383-493	5	4 – 5	195,000 13,709	165,000 - 225,000 11,600-15,819

4.3 Durability Properties

4.3.1 Wet-Dry Cycles

A total of three specimens were tested for 10 wet-dry cycles. Initial weights and dimensions (length and diameter) were measured and the cycles started with a 1-week wet cycle followed by a 1-week dry cycle. The changes in weight, length, diameter, and volume were determined following each wet-dry cycle and are reported in **Table 4-4**. After the first wet-dry cycle, the average change in weight, length, diameter, and volume was 0.04%, -0.25%, 0%, and -0.25%, respectively. The unit weight of the specimens increased over time, while the length of the specimens decreased. After the tenth wet-dry cycle, the average change in weight, length, diameter, and volume was 0.25%, -0.41%, 0%, and -0.41%, respectively. The unit weight of the specimens increased. The average strength of the grout after 10 wet-dry cycles was also determined and found to be an average of 6,531 psi (459 kg/cm²), approximately equal to the 3-day compressive strength of the grout, as shown in Table 4-3. The complete data set for these tests are included in **Appendix B, Tables B-7.1 and B-7.2**.

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) (g/cm ³)
1	0.04	-0.25	0.00	-0.25	0.99
2	0.13	-0.36	0.00	-0.36	0.99
3	0.17	-0.41	0.00	-0.41	0.99
4	0.13	-0.41	0.00	-0.41	0.99
5	0.25	-0.41	0.00	-0.41	0.99

Cycle Number (1)	Avg ΔW (2) (%)	Avg ΔL (2) (%)	Avg ΔD (2) (%)	Avg ΔV (2) (%)	Avg Density (2) (g/cm ³)
6	0.30	-0.41	0.00	-0.41	0.99
7	0.39	-0.41	0.00	-0.41	0.99
8	0.26	-0.36	0.00	-0.36	0.99
9	0.25	-0.37	0.00	-0.37	0.99
10	0.25	-0.41	0.00	-0.41	0.99

(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.

4.3.2 Chemical Resistance.

A total of nine specimens were tested for a period of 6 months. The initial weights and dimensions of the specimens were determined, and three specimens were exposed to each of solution of pH 2, 7, and 10. The test results are summarized in **Table 4-5**, and presented in **Appendix B, Table B-8**.

pH= 2 solution: After one month, the average change in weight, volume, and unit weight was 0.32%, 0.59%, and -0.27%, respectively. After 6 months, the average change in weight, volume, and unit weight was 1.38%, 1.70%, and -0.31%, respectively. The weight and volume increased over the 6-month period.

pH= 7 (tap water): After one month, the average change in weight, volume, and unit weight was 0.29%, 0.11%, and 0.18%, respectively. After 6 months, the average change in weight, volume, and unit weight was 1.24%, 0.47%, and 0.77%, respectively. The weight and volume increased over the 6-month period, as did the unit weight.

pH= 10 solution: After one month, the average change in weight, volume, and unit weight was 0.42%, -0.06%, and 0.48%, respectively. After 6 months, the average change in weight, volume, and unit weight was 1.24%, 0.47%, and 0.79%, respectively. The weight and volume increased over the 6-month period, as did the unit weight.

Table 4-5. 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	102.9		95.08		36.16		97.61		1.06	
30	103.2	0.32	94.95	-0.14	36.29	0.37	98.18	0.59	1.05	-0.27
90	104.0	1.06	94.90	-0.20	36.34	0.52	98.40	0.83	1.06	0.23
180	104.3	1.38	95.27	0.18	36.43	0.76	99.23	1.70	1.05	-0.31

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 7:										
0	104.7		96.74		36.30		100.10		1.05	
30	105.0	0.29	96.83	0.09	36.30	0.01	100.22	0.11	1.05	0.18
90	105.9	1.15	96.89	0.15	36.30	0.01	100.28	0.17	1.06	0.98
180	106.0	1.24	96.95	0.21	36.34	0.13	100.57	0.47	1.05	0.77
pH 10:										
0	98.4		91.22		36.28		94.20		1.04	
30	98.8	0.42	91.38	0.17	36.23	-0.12	94.16	-0.06	1.05	0.48
90	99.5	1.19	91.45	0.26	36.20	-0.21	94.09	-0.16	1.06	1.35
180	99.6	1.24	91.60	0.40	36.29	0.03	94.75	0.47	1.05	0.79

4.4 Environmental Properties—Leaching Study

A total of three specimens, of equal volumes and approximately equal weights, were exposed in an equal volume of tap water and the total organic carbon (TOC) was determined in each sample to measure the leaching of chemicals from the grout. The results found from 0.057 to 0.185 g of TOC/L, which translated to 0.0007 to 0.0023 g TOC/L/g grout, with a mean of 0.0017 g/L/g. The test results are reported in **Appendix B, Table B-9**. These data should be considered estimated values because of data uncertainty arising from incomplete QA/QC, as discussed in Section 5.4.

4.5 Grout/Substrate Interactions

The interaction between the grout and a concrete substrate was determined using prepared concrete bricks to which the grout was applied to form a sandwich, which was cured for varying lengths of time to demonstrate the cure time relationship between the concrete and the grout. Four sandwich specimens were evaluated at each of 30, 90 and 180 days following water curing, and three were evaluated after 180 days of wet-dry cycle curing. The cured specimens were tested on a load frame to determine the break strength of the grout-brick bond. The break type was evaluated to determine where the failure occurred, as described in **Table C-1** in **Appendix C**.

The failures observed in the specimens were all either Type 1 (i.e., a concrete brick failure, where the grout brick bond is intact) or a Type 4 (i.e., a bonding and substrate failure, where the brick fails at location of the applied grout, but the grout material remains intact). **Figure 4-1** shows the brick/grout specimen prior to testing, while **Figure 4-2** shows a typical Type 1 failure.

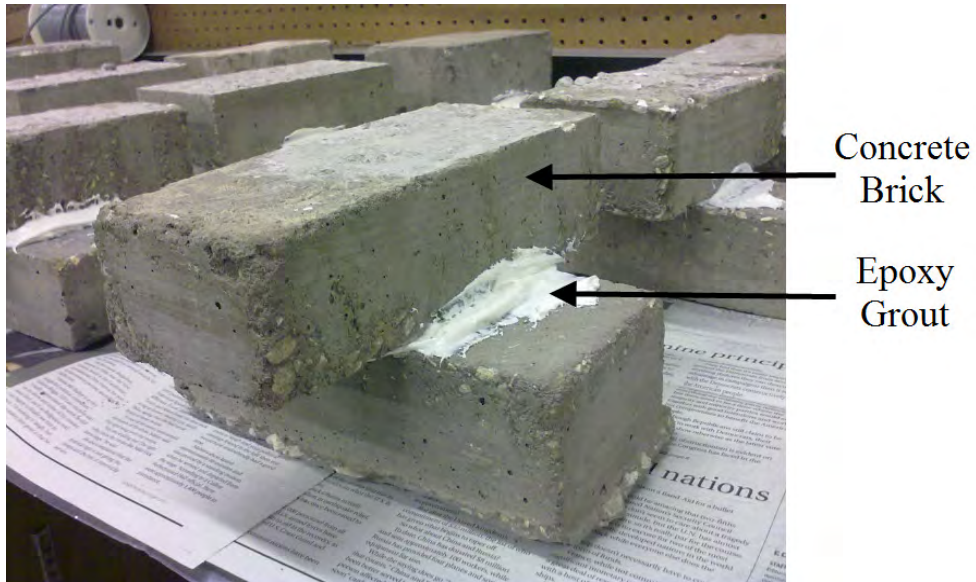


Figure 4-1. Sandwiched specimens for bonding test (Warren Environmental 301-04 epoxy grout).

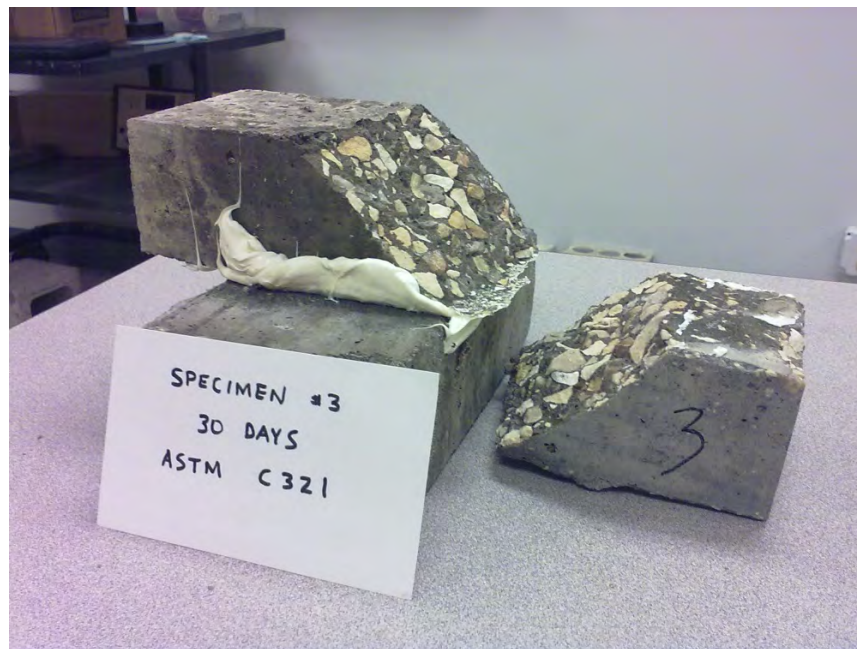
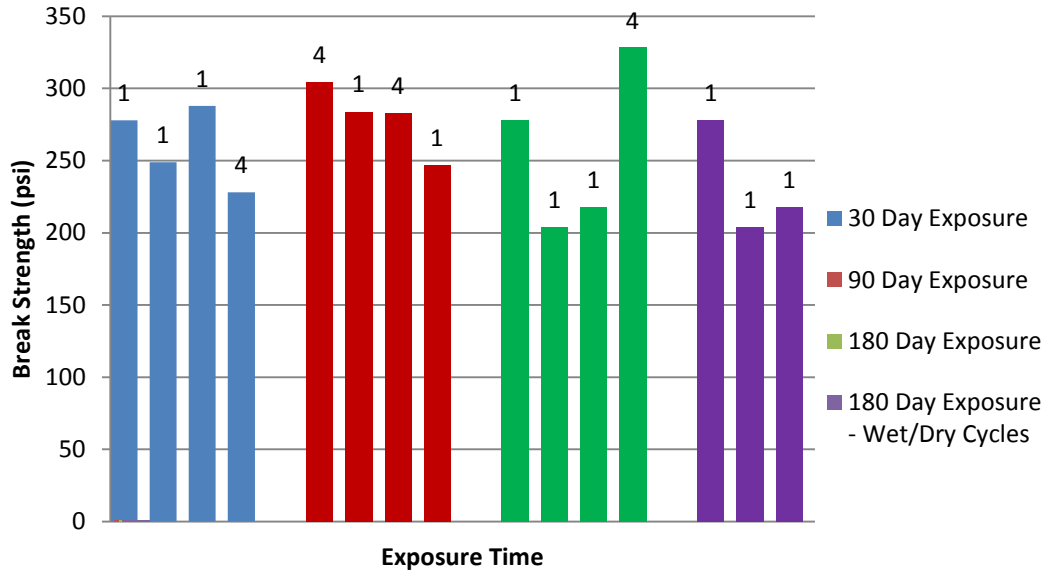


Figure 4-2. Typical failed specimen (Type 1 failure pattern).

The results of the bonding tests are presented in **Figure 4-3** and **Table 4-6**, with a more complete description of the results provided in **Appendix C**.



Note: Number at top of bars indicates the type of failure – 1 is a substrate (concrete block) failure, 4 is a bonding and substrate failure.

Figure 4-3. Results of grout-substrate bonding test.

Table 4-6. Summary of Bonding Strength Tests (CIGMAT CT-3)

Exposure Time (days)	Exposure Conditions	Failure Type ¹ – Number of Failures					Failure Strength (psi)/(kg/cm ²)	
		1	2	3	4	5	Range	Average
30	Water	3			1		228-288 16.0-20.2	260 18.3
90	Water	2			2		247-304 17.4-21.4	280 19.7
180	Water	3			1		204-329 14.3-23.1	257 18.1
	Wet-Dry Cycles	3					204-278 14.3-19.5	233 16.4

See Table C-1.

4.6 Model Test

Two replicate model tests were completed to simulate a leak repair for a concrete structure. **Figure 4-4 (a)** shows the defect created for evaluation of the grout for a concrete repair. The concrete rings were separated by spacers to create an open joint through which all of the water (100%) leaked out. The grout was placed within the ring space (**Figure 4-4 (b)**) by the grout supplier and was allowed cure before testing was initiated.



(a) Simulated cracked concrete.



(b) Repaired cracked concrete with epoxy grout.

Figure 4-4. Model test set up (a) Cracked concrete and (b) After grout repair.



Figure 4-5. Model 4 test setup.

After the grouted joint had cured, the joint was placed in a Plexiglas chamber (**Figure 4-5**), which was sealed to allow water to completely surround the grouted joint. Hydrostatic pressures of 3, 4, and 5 psi (0.21, 0.28 and 0.35 kg/cm²) were applied through the inlet to the Plexiglas

enclosure for 5 minutes at each pressure, and the water leaking through the grouted joint was collected and recorded. After two wet-dry cycles, the hydrostatic pressure tests were repeated.

The results of the model tests are summarized in **Table 4-7**. The model tests showed that the grouting with 301-04 was effective in significantly reducing or eliminating the leak in the cracked concrete (0 to 19.3 gallons/87.7 liters/day water leaks at 5 psi/0.35 kg/cm² water pressure) immediately after grouting and after two wet and dry cycles over period of one month (0 to 16.2 gallons/73.6 liters/day water leaks at 5 psi/0.35 kg/cm² water pressure).

Table 4-7. Model Test 4 Leak Rate Results (gallons/day)/(liters/day)

Hydrostatic Pressure (psi)	Replicate 1		Replicate 2	
	Initial Condition	Wet-Dry Cycle Condition	Initial Condition	Wet-Dry Cycle Condition
3	11.5/52.3	7.6/34.5	0.0	0.0
4	13.9/63.2	12.6/57.2	0.0	0.0
5	19.3/87.7	16.2/73.6	0.0	0.0

4.5 Summary of Observations

Combinations of laboratory tests, including two model tests, were performed over a six-month period with Warren Environmental 301-04 Epoxy Grout to determine its effectiveness in controlling leaks. Findings of the tests include:

- Model tests showed that the grouting with 301-04 was effective in significantly reducing or eliminating the leak in an open joint (0 to 19.3 gallons/87.7 liters/day water leaks at 5 psi/0.35 kg/cm² water pressure) immediately after grouting, and after two wet and dry cycles over period of one month (0 to 16.2 gallons/73.6 liters/day water leaks at 5 psi/0.35 kg/cm² water pressure). Before grouting, all of the applied water leaked out of the 1-inch gap.
- The setting time of the grout at room temperature (70°F/21°C) varied from 38 to 40 minutes. The average unit weight of the solid grout was 1.00 g/cm³. The average TOC in the leaching water of equal volume to the solid grout was 0.0017 g/L/g of grout.
- During the water absorption test, the weight change in the specimens varied from 0.09 to 0.17%, with an average of 0.14%. The volume change in the specimen varied from 0.03% to 0.05%, with a mean of 0.04%.
- The shrinkage at 90% humidity and 23°C temperature after 28 days of testing resulted in an average weight and volume change of 0.06% and 0.01%, respectively.
- The grout was impermeable under a hydraulic gradient of 100.
- The average strength, failure strain, and initial modulus after 3 days of curing were 6,591 psi (463 kg/cm²), 9%, and 225,000 psi (15,819 kg/cm²), respectively. The average strength, failure strain, and initial modulus after 28 days of curing was 6,180 psi (434 kg/cm²), 5%, and 195,000 psi (13,709 Kg/cm²), respectively.

- After the tenth wet-dry cycle, the average change in weight, length, diameter, and volume was 0.25%, -0.41%, 0%, and -0.41%, respectively. The unit weight of the specimens increased by 0.99%. The average strength of the grout after 10 wet-dry cycles was 6,531 psi (459 kg/cm²), similar to the compressive strength at 3 days cure time.
- After six months in a pH =2 solution (acid), the average change in unit weight and volume was -0.31% and 1.70%, respectively. After 6 months in a pH =7 solution (neutral tap water), the average change in unit weight and volume was 0.77% and 0.47%, respectively. After 6 months in a pH =10 solution (base), the average change in unit weight and volume was 0.79% and 0.47%, respectively.
- The bonding strength for water cured grout-concrete specimens did not vary significantly over a 6-month exposure period, with average strengths ranging from 257 to 280 psi (18.0 -19.7 kg/cm²); most of the specimen failures were Type 1 (substrate), with others being Type 4 (substrate failure with the grout intact).

After 6-months of wet-dry cycle exposure (10 cycles), the average bonding strength of grout-concrete specimens was 233 psi (16.4 kg/cm²), with all (100%) of the failures being Type 1.

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 concrete specimens 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 Requirements for Sample Preparation

5.1.1 Specimen Preparation

For each batch of concrete made at CIGMAT to perform the laboratory tests, specimens were tested to ensure their properties were within allowable ranges. The tests included unit weight and pulse velocity of the concrete prism specimens. Flexural strengths were also measured, where appropriate, to characterize the specimens. The target values for the unit weights of the specimens were maximum or minimum value of the batch within $\pm 20\%$ of the mean value of the batch. The property ranges for the concrete prisms are summarized in **Table 5-1**.

Table 5-1. Typical Properties for Concrete Specimens

Material	Unit Weight (pcf)	Pulse Velocity (ft/sec)	Flexural Strength (psi)
Concrete	138 – 149	12,600-15,800	720-960

5.1.2 Unit Weight and Pulse Velocity

The pulse velocity and unit weight were determined for 84 and 90 concrete prisms, respectively. For the concrete block specimens, the unit weight varied between 138 pcf (2212 kg/m³) and 149 pcf (2,388 kg/m³), with a mean value of 143 pcf (2292 kg/m³). The allowable range ($\pm 20\%$ of the mean value of the batch) is 114 pcf to 172 pcf. The concrete block specimens fell within this range. Pulse velocities ranged from 12,600 fps (3,840 m/sec) to 15,800 fps (4,845 m/sec), with a mean of 14,000 fps (4,367 m/sec), within the allowable range of 20% of the mean value of the batch.

There was no direct correlation between the pulse velocity and unit weight of concrete (**Figure A-1(a)**). The variation of pulse velocity was normally distributed (**Figure A-1(b)**).

5.1.3 Flexural Strength

While not required by the VTP, flexural strengths were determined for the concrete specimens, under both dry and wet conditions. This information provides further assurance that the specimens are acceptable for this verification. Two specimens each of dry and wet concrete

cylinders were tested for flexural strength. All specimens were cured for 28 days. The average flexural strength for the wet concrete was about 743 psi (52.2 kg/cm²) and was about 939 psi (66.0 kg/cm²) for the dry concrete. The flexural strengths of dry and wet concrete are summarized in **Table A-1** in **Appendix A**.

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 substrate and grouting specimens to be evaluated during preparation of the test specimens, as well as the number of coated specimens to be tested during the verification, were described in the VTP. The numbers that were completed during the verification testing are described in this section.

5.2.2.1 Specimen Preparation

The number (per the VTP) of each specimen to be used for characterization of the substrates is listed in **Table 5-2**. As there were multiple grouts being evaluated at the same time, CIGMAT prepared a batch of specimens to be grouted in the tests. The number of specimens characterized during preparation of the batch of specimens is indicated in parentheses for each material and test listed in **Table 5-2**.

Table 5-2. Number of Specimens Used for Each Characterization Test

Material	Number of Specimens Prepared for Use in Test				
	Unit weight	Pulse velocity	Water absorption	Flexure*	Compression*
Concrete Prisms	90	84	None	4	None

* Flexure and compression tests were performed for informational purposes only.

The number of specimens tested met, or exceeded the VTP requirement except for the pulse velocity for concrete prism specimens. The unit weight of concrete is the most important parameter to determine the quality of the concrete specimens, so every sample was tested for unit weight. The pulse velocity test—a special test not available for routine testing in test laboratories—was used at CIGMAT to check the quality of the concrete. The pulse velocity test results on the concrete specimens showed that there was nothing unusual about the specimens. As summarized in **Appendix A**, there was no direct correlation between the pulse velocity and unit weight of concrete, and the variation of pulse velocity was normally distributed.

5.2.2.2 Grout Properties

As described in Section 4.1, the number of properties tests completed during the evaluation were equal to, or greater than, required in Table 3-1 of the VTP. The exception was the viscosity test, as the grout is a solid at room temperature. Completeness for the grout properties was 100%.

5.2.2.3 Grout-Substrate Interaction Testing

The numbers (per the VTP) of grouted specimens to be evaluated for each substrate during the testing are indicated in **Table 5-3**. The bonding tests were completed over a period of six months to determine if there are changes in bonding strength with time. The total number of specimens for the entire test was the same as indicated in the VTP, resulting in 100% completeness.

Table 5-3. Total Number of Tests on Concrete-Grout Interaction Material

Exposure Time	Bonding Strength Tests	
	Water Cured	Wet-Dry Cycle
1 Month	4	0
3 Months	4	0
6 Months	4	3

5.2.2.4 Model Tests

Two replicate model tests were completed, 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 difficult. In this evaluation, analysis is made using four different parameters. Comparison of the results for multiple specimens prepared under similar conditions provides some indication of the variability of the specimen material and grout application methods, as well as the preparation of grout samples to determine unit weight. The results are shown in **Table 5-4**.

Table 5-4. Standard Deviation for Concrete Specimen Physical and Strength Properties and Grout Unit Weight

Properties	Number of Samples	Average Value	Standard Deviation
Unit Weight (pcf)/(g/cm ³)	90	143/2.29	3.2
Pulse Velocity (fps)/(m/sec)	84	14,000/4,267	873
Bonding Strength –all Type 1 failures ⁽¹⁾ (psi)/(kg/cm ²)	8	256/18.0	31.7
Grout Unit Weight (g/cm ³)	25	1.00	0.05

(1) Samples were cured for varying periods of time, from 30 to 180 days.

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

Behavior of Cement Concrete Bricks

In order to ensure the quality, samples of concrete bricks used in this study were tested and the results are summarized.

A.1. Unit Weight and Pulse Velocity

To ensure the quality of the concrete brick specimens used the unit weight and pulse velocity of the specimens were measured.

The variation of pulse velocity with unit weight is shown in Figure A1. The unit weight of concrete specimens varied between 138 pcf (2.21 g/cm^3) and 149 pcf (2.39 g/cm^3). The pulse velocity varied from 12,600 ft/sec (3,840 m/sec) to 15,800 ft/sec (4,815 m/sec). There was no direct correlation between the pulse velocity and unit weight of concrete (**Figure A-1(a)**). The variation of pulse velocity was normally distributed (**Figure A1(b)**).

A.2. Strength

Flexural strength of dry and wet concrete bricks are summarized in **Table A-1**. The flexural strength of concrete bricks varied from 743 to 939 psi (52.2 to 66.0 kg/cm^2) based on wet and dry condition, respectively.

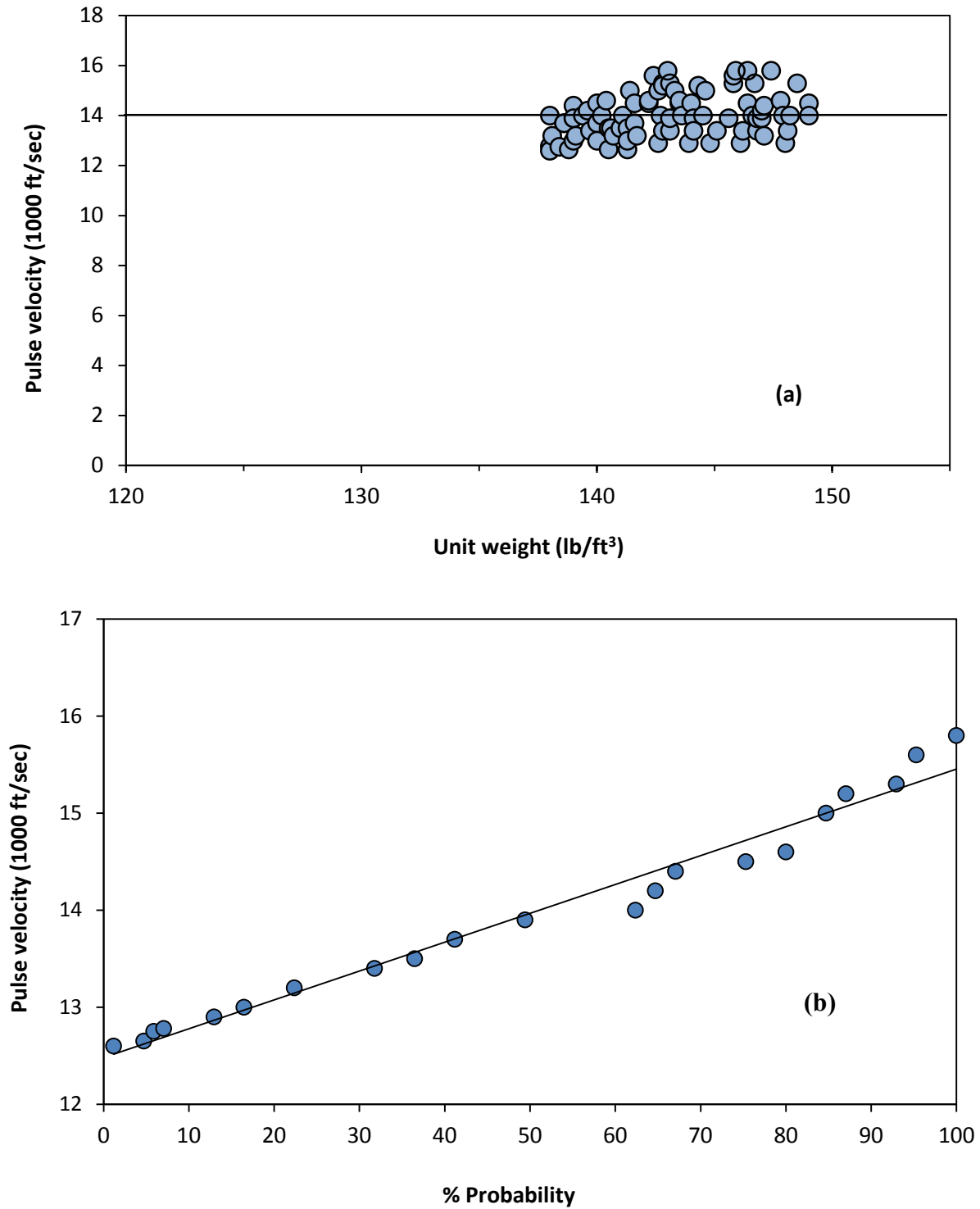


Figure A-1. Quality control for concrete brick specimens (a) Pulse velocity versus unit weight and (b) Distribution of pulse velocity.

Table A-1. Strengths of Concrete Bricks

Materials	Curing Time (days)	Compressive Strength (psi) Wet	Compressive Strength (psi) Dry	Flexural Strength (psi)/(kg/cm²) Dry	Flexural Strength (psi)/(kg/cm²) Wet
Concrete Block (No. Specimens)	28	Not Applicable	Not Applicable	939/66.0 (2)	743/52.2 (2)
Remarks	Concrete cured for 28 days.	Information For quality Control	Information For quality Control	Related to CIGMAT CT-3 (modified ASTM C321-94) Bonding Test	Related to CIGMAT CT-3 (modified ASTM C321-94) Bonding Test

Appendix B Characterization of Grout

Warren Environmental 301-04 Epoxy Grout Number of Grout Specimens Tested = 15

The grout specimens were tested for their working properties, physical properties, and leaching characteristics. In addition to the setting time test, several physical and mechanical property tests were performed on the grout. The leaching test included the measurement of total organic carbon (TOC) content in the water.

(a) Viscosity

At room temperature, the resin was a solid, and hence, the viscosity test was not performed.

(b) Setting Time

The gelling time testing was performed at room temperature and room humidity. A total of 6 samples were tested, and the results are summarized in **Table B-1**. The setting time varied from 38 to 40 minutes, with an average of 39 minutes and a coefficient of variation (COV) of 2%.

Table B-1. Summary of Setting Time Results

Specimen #	1t	2t	3t	4t	5t	6t
Gelling Time (min)	40	38	40	39	40	40

(c) Unit Weight

A total of 25 cylindrical specimens were tested, and the results are summarized in **Table B-2**. The grout unit weight varied from 0.91 to 1.09 g/cm³, with an average of 1.00 g/cm³ and a COV of 5%.

Table B-2 – Unit Weight Results for Warren Environmental 301-04 Epoxy Grout

Specimen #	Density (g/cm ³)	Specimen #	Density (g/cm ³)
1	1.03	14	0.94
2	0.99	15	0.94
3	1.09	16	1.00
4	1.05	17	0.97
5	0.91	18	1.05
6	1.07	19	0.95
7	0.95	20	0.96
8	0.95	21	1.06
9	0.93	22	1.06
10	1.05	23	1.09
11	1.05	24	1.02
12	1.01	25	0.96
13	1.03	Average	1.00
		SD	0.05
		COV	0.05

(d) Water Absorbance

The water absorption is a representation of the water diffusion characteristics of the grout. A total of 3 specimens were tested, and the results are summarized in **Table B-3**. The weight change in the specimens varied from 0.09 to 0.17%, with an average of 0.14%. The volume change in the specimen varied from 0.03% to 0.05%, with a mean of 0.04%

Table B-3. Water Absorbance Results

Exposure Time (days)	Specimen 41			Specimen 42			Specimen 43		
	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	0.98			0.98			0.99		
1	0.98	0.08	0.03	0.98	0.17	0.03	0.99	0.09	0.03
2	0.98	0.15	0.03	0.98	0.17	0.03	0.99	0.09	0.06
3	0.98	0.15	0.05	0.98	0.17	0.03	0.99	0.09	0.06
4	0.98	0.15	0.05	0.98	0.17	0.05	0.99	0.09	0.03

(e) Shrinkage Test

Total of 3 specimens were tested for 28 days. The weight change varied from 0 to 0.09%, with an average value of 0.06%. The volume change varied from 0 to 0.04%, with an average of 0.01%.

Table B-4. Shrinkage test results for Warren Environmental 301-04 Epoxy Grout

Specimen #		Weight (g)	Length (mm)	Diameter (mm)	Volume (cm ³)	Density (g/cm ³)
Initial	40	116.3	117.43	36.10	120.19	0.97
	39	110.9	106.73	36.63	112.47	0.99
	38	110.1	110.23	36.43	114.90	0.96
After 28 Days	40	116.4	117.43	36.10	120.19	0.97
	39	111	106.77	36.63	112.52	0.99
	38	110.1	110.23	36.43	114.90	0.96
		ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm ³)
After 28 Days	40	0.09	0.00	0.00	0.00	0.97
	39	0.09	0.04	0.00	0.04	0.99
	38	0.00	0.00	0.00	0.00	0.96
	Average	0.06	0.01	0.00	0.01	0.97

(f) Permeability

Three grout specimens were tested for permeability under a hydraulic gradient of 100. A total of three specimens were tested, with no observed passage of water over a 72 hour period. The results of the testing are summarized in **Table B-5**. Based on these results, the permeability of the grout was zero.

Table B-5. Permeability Test Results

Moisture content and specimen characteristics	Units	Specimen Number		
		1	2	3
Specimen		1	2	3
Aver. diam.	(mm)	38.10	38.10	38.10
Init. Height	(mm)	63.50	63.50	63.50
Area	(cm ²)	11.40	11.40	11.40
Total weight	(g)	72.2	72.0	71.4
Total volume	(cm ³)	72.39	72.39	72.39
Total unit weight	(g/cm ³)	1.00	0.99	0.99
Curing time	(days)	7	7	7
Discharge (Q) (mL)	15 min	0	0	0
	30 min	0	0	0
	1 hrs	0	0	0
	2hrs	0	0	0
	4hrs	0	0	0
	8hrs	0	0	0
	12 hrs	0	0	0
	24 hrs	0	0	0
	48 hrs	0	0	0
	72 hrs	0	0	0
Permeability (K)	cm/s	0	0	0

(g) Compressive Strength and Stress-Strain Relationship

The compressive properties (strength, failure strain and initial modulus) were measured over period of 90 days. A total of 11 specimens were tested, and the results are summarized in **Table B-6**. The average strength, failure strain, and initial modulus after 3 days of curing were 6,591 psi (463 kg/cm²), 9%, and 225,000 psi (15,819 kg/cm²), respectively. The average strength, failure strain, and initial modulus after 28 days of curing were 6,180 psi (434 kg/cm²), 5%, and 195,000 psi (13,709 kg/cm²), respectively.

Table B-6. Summary of Compressive Strength Properties with Curing Time

Specimen	Curing time (days)	Strength (psi)/(kg/cm ²)	Failure Strain	Initial Modulus (psi)/(kg/cm ²)
1a	3	6,310/443	0.10	200,000/14,061
2a	3	7,356/517	0.08	250,000/17,576
3a	3	6,105/429	0.10	225,000/15,819
Average		6,591/463	0.09	225,000/15,819
4a	7	5,304/372	0.06	215,000/15,116
5a	7	7,592/533	0.07	240,000/16,873
6a	7	6,311/443	0.03	225,000/15,819
Average		6,402/450	0.05	226,667/15,936
7a	28	5,451/383	0.04	175,000/12,303
8a	28	6,755/474	0.05	220,000/15,467
9a	28	6,203/436	0.05	190,000/13,358
10a	28	7,022/493	0.05	225,000/15,819
11a	28	5,470/384	0.05	165,000/11,600
Average		6,180/434	0.05	195,000/13,709

(h) Wet-Dry Cycles

A total of three specimens were tested for 10 cycles. The cycles started with a wet cycle first. The change in weight, length, diameter, and volume are reported in Table B-7. After the first wet-dry cycle, the average change in weight, length, diameter, and volume was 0.04%, -0.25%, 0%, and -0.25%, respectively. The unit weight of the specimens increased. After the tenth wet-dry cycle, the average change in weight, length, diameter, and volume was 0.25%, -0.41%, 0%, and -0.41%, respectively. The unit weight of the specimens increased. The average strength of the grout after 10 wet-dry cycles was 6,531 psi (459 kg/cm²); hence, the specimen strength was not affected after 10 wet-dry cycles.

Table B-7.1. Wet-Dry cycle test results for Warren Environmental 301-04 Epoxy Grout

Original	Specimen #	Weight (g)	Length (mm)	Diameter (mm)	Volume (cm ³)	Density (g/cm ³)
	#18	85.7	79.33	36.20	81.65	1.05
	#19	68.6	69.83	36.20	71.87	0.95
	#20	77.8	79.07	36.20	81.38	0.96

Cycle 1	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm ³)
	#18	0.00	-0.16	0.00	-0.16	1.05
	#19	0.00	-0.14	0.00	-0.14	0.96
	#20	0.13	-0.43	0.00	-0.43	0.96
Average		0.04	-0.25	0.00	-0.25	0.99

Cycle 2	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm ³)
	#18	0.12	-0.25	0.00	-0.25	1.05
	#19	0.15	-0.33	0.00	-0.33	0.96
	#20	0.13	-0.51	0.00	-0.51	0.96
Average		0.13	-0.36	0.00	-0.36	0.99

Cycle 3	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm ³)
	#18	0.23	-0.29	0.00	-0.29	1.06
	#19	0.15	-0.43	0.00	-0.43	0.96
	#20	0.13	-0.51	0.00	-0.51	0.96
Average		0.17	-0.41	0.00	-0.41	0.99

Cycle 4	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm ³)
	#18	0.12	-0.29	0.00	-0.29	1.05
	#19	0.15	-0.43	0.00	-0.43	0.96
	#20	0.13	-0.51	0.00	-0.51	0.96
Average		0.13	-0.41	0.00	-0.41	0.99

Cycle 5	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm ³)
	#18	0.23	-0.29	0.00	-0.29	1.06
	#19	0.15	-0.43	0.00	-0.43	0.96
	#20	0.39	-0.51	0.00	-0.51	0.96
	Average	0.25	-0.41	0.00	-0.41	0.99

Cycle 6	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm ³)
	#18	0.23	-0.33	0.00	-0.33	1.06
	#19	0.29	-0.43	0.00	-0.43	0.96
	#20	0.39	-0.47	0.00	-0.47	0.96
	Average	0.30	-0.41	0.00	-0.41	0.99

Cycle 7	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm ³)
	#18	0.23	-0.29	0.00	-0.29	1.06
	#19	0.44	-0.47	0.00	-0.47	0.96
	#20	0.51	-0.47	0.00	-0.47	0.97
	Average	0.39	-0.41	0.00	-0.41	0.99

Cycle 8	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm ³)
	#18	0.12	-0.29	0.00	-0.29	1.05
	#19	0.29	-0.33	0.00	-0.33	0.96
	#20	0.39	-0.47	0.00	-0.47	0.96
	Average	0.26	-0.36	0.00	-0.36	0.99

Cycle 9	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm ³)
	#18	0.23	-0.33	0.00	-0.33	1.06
	#19	0.15	-0.29	0.00	-0.29	0.96
	#20	0.39	-0.51	0.00	-0.51	0.96
	Average	0.25	-0.37	0.00	-0.37	0.99

Cycle 10	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm ³)
	#18	0.23	-0.29	0.00	-0.29	1.06
	#19	0.15	-0.43	0.00	-0.43	0.96
	#20	0.39	-0.51	0.00	-0.51	0.96
	Average	0.25	-0.41	0.00	-0.41	0.99

Table B-7.2. Compressive Strength after Wet-dry Cycles for Warren Environmental 301-04 Epoxy Grout

Specimen #	Compressive Strength (psi)/(kg/cm ²)
#18	6,407/450
#19	6,605/464
#20	6,580/462
Average	6,531/459

(i) Chemical Resistance

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

pH= 2 solution: After 1 month, the average change in weight, volume, and unit weight was 0.32%, 0.59%, and -0.27%, respectively. After 6 months, the average change in weight, volume, and unit weight was 1.38%, 1.70%, and -0.31%, respectively. The weight and volume increased and the unit weight decreased over the 6-month period.

pH= 7 -water: After 1 month, the average change in weight, volume and unit weight was 0.29%, 0.11%, and 0.18%, respectively. After 6 months, the average change in weight, volume, and unit weight was 1.24%, 0.47%, and 0.77%, respectively. The weight, volume and unit weight increased over the 6-month period.

pH= 10 solution: After 1 month, the average change in weight, volume, and unit weight was 0.42%, -0.06%, and 0.48%, respectively. After 6 months, the average change in weight, volume, and unit weight was 1.24%, 0.47%, and 0.79%. respectively. The weight, volume and unit weight increased over the 6-month period.

Table B-8. Chemical Resistance Test Results

	Specimen #	Weight (g)	Length (mm)	Diameter (mm)	Volume (cm ³)	Density (g/cm ³)
Original (pH=2)	#22	97.3	88.87	36.20	91.47	1.06
	#23	100.1	89.67	36.17	92.14	1.09
	#24	111.3	106.70	36.10	109.21	1.02
	Average	102.90	95.08	36.16	97.61	1.06

30 days (pH=2)	#22	97.6	88.70	36.27	91.64	1.06
	#23	100.3	89.43	36.43	93.22	1.08
	#24	111.8	106.73	36.17	109.67	1.02
	Average	103.2	94.95	36.29	98.18	1.05
	% Change	0.32	-0.14	0.37	0.59	-0.27

3 months (pH=2)	#22	98.3	88.63	36.33	91.88	1.07
	#23	100.9	89.37	36.50	93.51	1.08
	#24	112.8	106.70	36.20	109.82	1.03
	Average	104.0	94.90	36.34	98.40	1.06
	% Change	1.06	-0.20	0.52	0.83	0.23

6 months (pH=2)	#22	98.6	88.60	36.53	92.86	1.06
	#23	101.2	90.03	36.53	94.36	1.07
	#24	113.2	107.17	36.23	110.48	1.02
	Average	104.3	95.27	36.43	99.23	1.05
	% Change	1.38	0.18	0.76	1.70	-0.31

	Specimen #	Weight (g)	Length (mm)	Diameter (mm)	Volume (cm ³)	Density (g/cm ³)
Original (pH=7)	#10	102.2	94.33	36.33	97.78	1.05
	#13	106.4	99.23	36.33	102.86	1.03
	#21	105.6	96.67	36.23	99.66	1.06
	Average	104.73	96.74	36.30	100.10	1.05

30 days (pH=7)	#10	102.6	94.23	36.33	97.68	1.05
	#13	106.7	99.47	36.37	103.34	1.03
	#21	105.8	96.80	36.20	99.63	1.06
	Average	105.0	96.83	36.30	100.22	1.05
	% Change	0.29	0.09	0.01	0.11	0.18

	Specimen #	Weight (g)	Length (mm)	Diameter (mm)	Volume (cm ³)	Density (g/cm ³)
3 months (pH=7)	#10	103.6	94.20	36.33	97.65	1.06
	#13	107.5	99.60	36.40	103.65	1.04
	#21	106.7	96.87	36.17	99.54	1.07
	Average	105.9	96.89	36.30	100.28	1.06
	% Change	1.15	0.15	0.01	0.17	0.98
6 months (pH=7)	#10	103.5	94.47	36.40	98.31	1.05
	#13	107.7	99.37	36.43	103.58	1.04
	#21	106.9	97.00	36.20	99.83	1.07
	Average	106.0	96.95	36.34	100.57	1.05
	% Change	1.24	0.21	0.13	0.47	0.77
Original (pH=10)	#6	106.2	96.80	36.20	99.63	1.07
	#11	105.4	97.93	36.10	100.24	1.05
	#12	83.5	78.93	36.53	82.72	1.01
	Average	98.37	91.22	36.28	94.20	1.04
30 days (pH=10)	#6	106.6	97.03	36.20	99.86	1.07
	#11	105.7	98.00	36.10	100.31	1.05
	#12	84.0	79.10	36.40	82.31	1.02
	Average	98.8	91.38	36.23	94.16	1.05
	% Change	0.42	0.17	-0.12	-0.06	0.48
3 months (pH=10)	#6	107.1	97.13	36.20	99.97	1.07
	#11	106.5	98.03	36.10	100.34	1.06
	#12	84.9	79.20	36.30	81.96	1.04
	Average	99.5	91.45	36.20	94.09	1.06
	% Change	1.19	0.26	-0.21	-0.16	1.35
6 months (pH=10)	#6	107.3	97.30	36.40	101.25	1.06
	#11	106.6	98.40	36.23	101.44	1.05
	#12	84.8	79.10	36.23	81.55	1.04
	Average	99.6	91.60	36.29	94.75	1.05
	% Change	1.24	0.40	0.03	0.47	0.79

(j) Leaching Study

A total of 3 specimens were tested in equal volume of water and total organic carbon (TOC). The results are reported in Table B.9. The average TOC measured varied from 0.0007 to 0.0023 g/L/g of grout, with a mean of 0.0017 g/L/g grout. These data should be considered estimated values because of data uncertainty arising from incomplete QA/QC, as discussed in Section 5.4.

Summary: The average TOC in the leaching solution was 0.0017 g/L/g of grout.

Table B-9. Summary of Leaching Test Results

Specimen #	Material	Weight (g)	Volume of Grout (mL)	Volume of Tap water (mL)	TOC (g/L)	TOC (g/L/g grout)
1	Tap Water			100	0.026	
2	Grout	79.7	60	60	0.185	0.0023
3	Grout	75.3	60	60	0.151	0.0020
4	Grout	77.7	60	60	0.057	0.0007
Average						0.0017

Appendix C

Grout-Substrate (Concrete) Interaction

Number of Tests = 15

Total of 15 sandwiched bonding tests (CIGMAT CT-3) were performed after for 30, 90 and 180 days. The failures were characterized based on the Types of failures identified in **Table C-1**.

Table C-1. Failure Types for CIGMAT CT-3 Test

Failure Type	Description	CIGMAT CT 3 (ASTM C321 Test)
Type 1	Substrate Failure	<p style="font-size: small;">Concrete/Clay Brick Coating</p>
Type 2	Coating Failure	<p style="font-size: small;">Concrete/Clay Brick Coating</p>
Type 3	Bonding Failure	<p style="font-size: small;">Concrete/Clay Brick Coating</p>
Type 4	Bonding and Substrate Failure	<p style="font-size: small;">Concrete/Clay Brick Coating</p>
Type 5	Bonding and Coating Failure	<p style="font-size: small;">Concrete/Clay Brick Coating</p>

(a) After 1 Month

A total of 4 specimens were tested. The results are summarized in **Table C-2**. Based on the test results, 75% of the failures were Type 1, and 25% were Type 4. The bonding strength varied from 228 to 288 psi (16.0 to 20.2 kg/cm²). The average strength measured was 260 psi (18.3 kg/cm²).

Summary: The average bonding strength was 260 psi (18.3 kg/cm²), and 75% of the failures were Type 1.

Table C-2. Summary of One Month Bonding Test Results

Specimen #	Curing Time (days)	Failure Modes					Max Strength (psi)/(kg/cm ²)
		Type 1	Type 2	Type 3	Type 4	Type 5	
1	30	X					278/19.5
2	30	X					249/17.5
3	30	X					288/20.2
4	30				X		228/16.0
Total No. (% Failure)		3 (75%)			1 (25%)		4 successful tests.

(b) 3 Months

A total of 4 specimens were tested. The results are summarized in **Table C-3**. Based on the test results, 50% of the failures were Type 1, and 50% were Type 4. The bonding strength varied from 247 to 304 psi (17.4 to 21.4 kg/cm²). The average strength measured was 280 psi (19.7 kg/cm²).

Summary: The average bonding strength was 280 psi (19.7 kg/cm²), 50% of the failures were Type 1, and the other 50% were Type 4.

Table C-3. Summary of 3-Month Bonding Test Results

Specimen #	Curing Time (days)	Failure Modes					Max Strength (psi)/(kg/cm ²)
		Type 1	Type 2	Type 3	Type 4	Type 5	
5	90				X		304/21.4
6	90	X					284/20.0
7	90				X		283/19.9
8	90	X					247/17.4
Total No. (% Failure)		2 (50%)			2 (50%)		4 successful tests.

(c) 6 Months

A total of 4 specimens were tested. The results are summarized in **Table C-4**. Based on the test results, 75% of the failures were Type 1, and 25% of the failures were Type 4. The bonding strength varied from 218 to 329 psi (15.3 to 23.1 kg/cm²). The average strength measured was 257 psi (18.1 kg/cm²).

Summary: The average bonding strength was 257 psi (18.1 kg/cm²), and 75% of the failures were Type 1.

Table C-4. Summary of 6-Month Bonding Test Results

Specimen #	Curing Time (days)	Failure Modes					Max Strength (psi)/(kg/cm ²)
		Type 1	Type 2	Type 3	Type 4	Type 5	
9	180	X					278/19.5
10	180	X					204/14.3
11	180	X					218/15.3
12	180				X		329/23.1
Total No. (% Failure)		3 (75%)			1 (25%)		4 successful tests.

(d) 6 Months (Wet-Dry)

A total of 4 specimens were tested. The results are summarized in **Table C-5**. Based on the test results, 100% of the failures were Type 1. The bonding strength varied from 204 to 278 psi (14.3 to 19.5 kg/cm²). The average strength measured was 233 psi (16.4 kg/cm²).

Summary: The average bonding strength was 233 psi (16.4 kg/cm²), and 100% of the failures were Type 1.

Table C-5. Summary of 6-Month Bonding Test (Wet-dry Cycles) Results

Specimen #	Curing Time (days)	Failure Modes					Max Strength (psi)/(kg/cm ²)
		Type 1	Type 2	Type 3	Type 4	Type 5	
13	180	X					278/19.5
14	180	X					204/14.3
15	180	X					218/15.3
Total No. (% Failure)		3 (100%)					3 successful tests.

Appendix D
Grout Vendor Data Sheet

GROUT VENDOR DATA SHEET**Grout Product Name:** Warren Environmental Mastic 301-04**Grout Product Manufacturer Name and Address:** Warren Environmental Inc.P.O. Box 1206, Carver, MA 02330**Grout Type:** Epoxy Grout**Chemical Formula:** 100% Solids Epoxy

TESTING METHOD	MANUFACTURER'S RESULTS
Type of Resin, Initiator and/or Promotor	100%
Grout Mix (by weigh or volume)	2:1 by volume
Resin Viscosity (ASTM _____)	150,000 – 250,000 cps
Flash Point (ASTM D 93/ _____)	> 235 degrees F
Tensile Adhesion to Concrete and Clay Brick (ASTM _____)	400 psi or greater
Chemical Resistance (ASTM _____) (NaOH, 3% H ₂ SO ₄ or others)	See manufacturer's data sheet.
Volatile Organic Compounds – VOCs (ASTM _____)	None

WORKER SAFETY	RESULT/REQUIREMENT
Flammability Rating	Base resin has passed airline industry standards
Known Carcinogenic Content	None
Other Hazards (Corrosive)	None
MSDS Sheet Availability	Yes

ENVIRONMENTAL CHARACTERISTICS	RESULT/REQUIREMENT
Heavy Metal Content (w/w)	None
Leaching from Cured Grouts	Certified to NSF/ANSI Standard 61
Disposal of Cured Grouts	Cured material is not hazardous.

DATA SHEET ON PROPERTIES OF GROUT (Continued)

APPLICATION CHARACTERISTICS	RESULT/REQUIREMENTS
Minimum Application Temperature	30° F
Maximum Application Temperature	200° F
Minimum Cure Time before Immersion into Service	
Type of Preparation Before Grouting	See mixing instructions
Grouting Pressure	Not applicable

VENDOR EXPERIENCE	COMMENTS
Length of Time the Grout in Use	12 years
Applicator Training and Qualification Program	Yes
QA/QC Program for Grouts in the Field	Yes

ADDITIONAL COMMENTS (Including Case Studies on Performance)