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Environmental Technology Verification Report Grouts for Wastewater Collection Systems

Separation System Consultants, Inc. (SSCI) GST #3 Grout

Prepared by

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

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Verification of Grouts for Rehabilitation of Wastewater Collection Systems

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NOTICE

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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
gpm	Gallon(s) per minute
GP	Generic Protocol
HP	Horsepower
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
kN	Kilonewton(s)
L	Liter
lbs	Pounds
MDL	Minimum Detection Level
min	Minute(s)
NRMRL	National Risk Management Research Laboratory
m/sec	Meters 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 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 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 Separation Systems Consultants, Inc.'s (SSCI's) supplied GST #3 grout under laboratory conditions at the Center for Innovative Grouting Materials and Technology (CIGMAT) Laboratories at the University of Houston. Testing was conducted on the grout and a grouted substrate over a period of 6 months to evaluate the grout's 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 one month of curing time. Testing also included evaluation of the bonding strength between the grout and concrete substrate specimens. Finally, two model tests were performed to determine the effectiveness of the grout in reducing leakage in cracked concrete.

Testing resulted in the following measurements and observations for SSCI's GST #3 grout:

- Model tests showed that the grouting with GST #3 grout was effective in significantly reducing or eliminating the leak in the cracked concrete (0 to 17.2 gallons/65.1liters/day water leaks at 5 psi/3.45 x 10^{-2}MPa water pressure) immediately after grouting and after two wet-dry cycles over period of 1 month (0 to 13.6 gallons/13.6liters/day water leaks at 5 psi/3.45 x 10^{-2}MPa water pressure). Prior to grouting, all of the water leaked out of the cracked concrete. The setting time of the grout at room temperature (70^{o}F/ 21^{o}C) varied from 2.5 to 2.6 minutes. The average unit weight of the solid grout was 0.56 g/cm^3. The average total organic content (TOC) in the leaching water of equal volume to the solid grout was 0.35 g/L/g of grout.
- During the water absorption test (under saturated conditions), the weight change in the specimens varied from 35.67% to 40.18 %, with an average of 37.57%. The volume change in the specimens varied from 23.45% to 29.47%, with a mean of 26.79%
- The shrinkage testing, at 90% humidity and (73^{o}F/ 23^{o}C temperature, after 28 days of testing resulted in an average gain in weight and volume of 21.84% and 19.52%, respectively.
- The grout was found to be impermeable under a hydraulic gradient of 100. The average strength, failure strain, and initial modulus after 3 days of curing was 98 psi (0.677 MPa), 60%, and 373 psi (26.2 kg/cm^2), respectively. The average strength, failure strain, and

initial modulus after 28 days of curing was 101 psi (0.70 MPa), 51%, and 410 psi (2.83 MPa), respectively.

- After the tenth wet-dry cycle, the average change in weight, length, diameter, and volume was 41.46%, 0.62%, 0%, and 3.78%, respectively. The unit weight of the specimens increased by 6.7%. The average strength of the grout after 10 wet-dry cycles was 89 psi (0.61 MPa).
- The weight and volume increased over the 6-month period in all three pH solutions. After 6 months in a pH =2 solution (acid), the average change in unit weight and volume was 92.69% and 26.02%, respectively. After 6 months in a pH =7 solution (neutral), the average change in unit weight and volume was 92.00% and 28.63%, respectively. After 6 months in a pH =10 solution (base), the average change in unit weight and volume was 63.76% and 32.71%, respectively.
- After 6 months in water, the average bonding strength was 43 psi (3.0 kg/cm^2), and all (100%) of the failures were Type 3 (bonding failure, where the bond between brick and grout failed). After 6 months of the wet-dry cycle test, the average bonding strength was 83 psi (0.57 MPa), and all (100%) of the failures were also Type 3.

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 the six centers under the 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 Separation Systems Consultants, Inc.’s (SSCI’s) GST #3 polyurethane grout was completed following the *Generic Test Plan for Verification of Grouts for Wastewater Collection Systems, 2009* (henceforth referred to as the GTP). The GTP was used to develop a product-specific verification test plan (VTP) for the SSCI GST #3 polyurethane 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 (CIGMAT), the TO, and the Vendor to prepare and approve a product-specific VTP using the Generic Test Plan 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 and verification statement; and
- Provide quality assurance (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 developed with financial and QA 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 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 the Center for Innovative Grouting Materials and Technology (CIGMAT) at the University of Houston. The primary responsibilities of the TO are the following:

- Coordinate with the Verification Organization (VO) and Vendor relative to preparing and finalizing the product-specific 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. The 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 (Separation Systems Consultants, Inc.)

- Provide the TO with pre-grout samples for verification;
- Complete a product data sheet prior to testing;
- Provide start-up services and 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 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 the rehabilitation of cracked concrete for leak control. Specific testing objectives are the following:

- Evaluate the effectiveness of the grout to control the leak at a simulated concrete crack; 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 at 4800 Calhoun Road. The CIGMAT Laboratories and affiliated facilities are equipped with devices that can perform all of the grouting tests in this test plan. 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 SSCI GST #3 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 leak control in cracked concrete over a period of time.

Section 2
Grout Material Description

The grout material evaluated in this verification was the GST #3 from Separation Systems Consultants, Inc. (SSCI). The grout is a polymer solution that cures when reacted with water. Further information about SSCI may be found on the company's web site at http://www.sscienvironmental.com. GST #3 grout reacts freely with water to form a strong film, gel, or foam of polyurethane. GST #3's intended use would be to prevent water infiltration into sub-grade structures and pipes. The grout is nonflammable and is a durable and versatile elastic foam or gel. It is used for heavy or light flow conditions, as well as for under water applications. GST #3 is sensitive to moisture and moderately sensitive to high storage temperatures, and it should be stored in a dry area between 40°F (4.4^{o}C) and 80°F (26.6^{o}C). GST #3 should be properly removed from all application equipment due to the high risk of moisture contamination..

The solidified GST #3 polyurethane grout was yellow in color, as shown in ***Figure 2-1***.

Figure 2-1. Polyurethane grout specimen (GST #3).

Section 3
Methods and Test Procedures

The testing involved characterization of the grout material and bonding strength to concrete. In addition, model tests were performed to determine the effectiveness of the grout 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 were 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 existing American Society of Testing and Materials (ASTM) test procedures to determine the grout properties, CIGMAT had 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 that was utilized to make the grout test specimens. Specimens were prepared with a resin-to-water ratio of 9:1 and 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 ± 2°C (room temperature) and 50% ± 5% humidity.

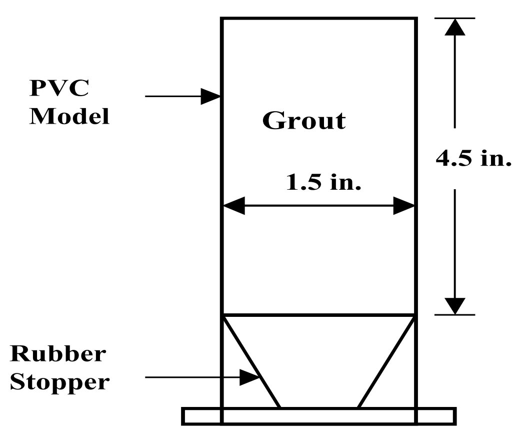


Figure 3-1. Typical mold used for preparing grout specimens.

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
	Unit Weight	23°C	CIGMAT GR 1-04	12
Physical and Mechanical Properties	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	17
	Wet-Dry Cycle	Number of cycles	CIGMAT GR 3-04	3
Durability Properties	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
Bonding Strength	Wet condition	Concrete brick cured under water	CIGMAT CT 3-00	11
	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 the bonding test was completed. The reported data include the number of specimens tested, the age of specimen at the time of the test, average bond strength with standard deviation, and types of failures.

3.1.2 Grout Curing Properties

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

3.1.2.1 Viscosity

Viscosity is a typical descriptor of the flow characteristic of a grout material. The GST #3 grout was expanding and solidifying relatively quickly, so the viscosity test was not performed.

3.1.2.2 Setting (Gel) Time

No ASTM standard method is available to determine the gel time for epoxy grouts. Consequently, 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.

3.1.3 Physical and Mechanical Properties

To obtain initial grout characterization information, 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.

3.1.3.1 Unit Weight (Density)

Solidified grout specimens were used to determine the unit weight of the grout. The determination was completed per CIGMAT GR 1-00 for grout specimens. Unit weight was calculated using the weight and volume of the specimens. A minimum of three replicates were evaluated for unit weight.

3.1.3.2 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 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 results reported for this testing include the time of immersion, the initial characteristics of the specimens, and the weight and volume changes with time.

3.1.3.3 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	23ºC ± 2ºC for 28 days in zip lock bags (RH = 90%± 5%)

3.1.3.4 Permeability

Solidified grout specimens were used to determine the grout's 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 of three replicate samples were completed at room temperature and humidity.

3.1.3.5 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 failed.

3.1.4 Durability Properties

3.1.4.1 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. 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 grout specimens.

3.1.4.2 Chemical Resistance

This test evaluated 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 and 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 was 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.

3.1.5 Environmental Properties—Leaching Test

Potential contaminant leaching from solidified grout was determined by analyzing water exposed to the grout for total organic carbon (TOC) and lead. Lead is an issue with inorganic grout, but is not the case with a polyurethane grout as the GST #3 grout, so lead evaluation was not required. Three test replicates, using cylindrical grout specimens, were exposed to tap water in individual exposure jars 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 and water volume so that there was an adequate volume of exposure 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 4ºC, pH<2 HNO_3, six 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 (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 (where the area between concrete bricks/prisms was grouted), as selected by the Vendor. In addition, bonded configurations prepared according to CIGMAT CT 3-00 were also subjected to wet-dry cycle test.

3.3 Model Test

SSCI selected the Model Test related to leak control in cracked concrete for this study.

3.3.1 Model Test: Concrete Leak Repair

In order to simulate a leak in a concrete structure, this model test (***Figure 3-2***) used 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 one inch apart and the opening was grouted by the Vendor. After the Vendor-specified curing period (at least 3 days), the grouted joint was subjected to hydrostatic pressure testing to determine the leak rate, as outlined in Section 3.3.2.

Procedure for preparing a concrete leak repair joint for Model Test:

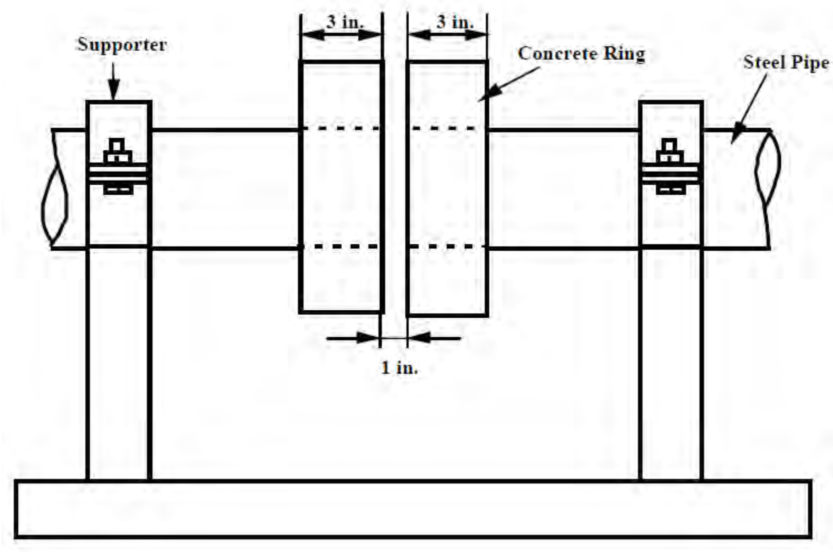
- The gap between the concrete rings on the testing rig was set one inch apart.
- SSCI applied the grout in the gap, in accordance with their SOP.
- After the grout cured, testing was initiated using the procedures outlined in the Section 3.3.2.

3.3.2 Model Test Procedures

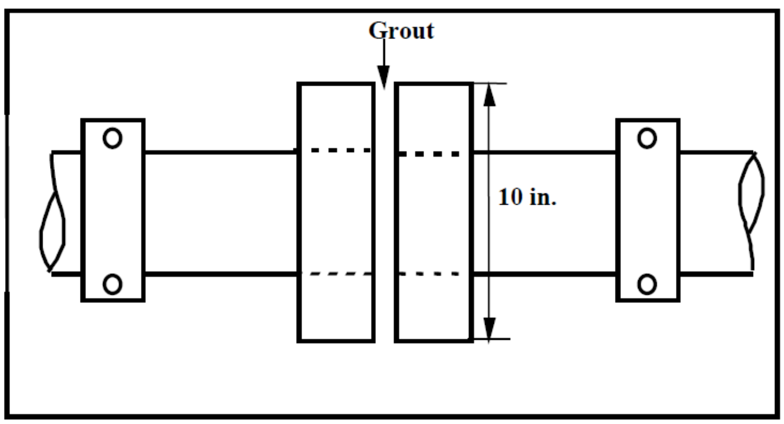
The grouted concrete disks were subjected to the following test procedures:

1. Apply hydrostatic pressure of 3 psi (2.1 x 10^{-2} MPA) 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 (2.76 x 10^{-2}MPa).
3. Repeat Step 1 at a hydrostatic pressure of 5 psi (3.45 x 10^{-2} MPa_).
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 SSCI GST #3 grout to characterize the material and provide information on how the grout will perform under various application conditions. 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 grout/substrate interactions. The results of these tests are presented in this section.

4.1 Grout Properties

4.1.1 Working properties

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

4.1.1.1 Viscosity

As the GST #3 grout was expanding and solidifying relatively quickly, 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 6 samples were tested, and the results are summarized in ***Table 4-1***. Setting time varied from 2.5 to 2.6 minutes, with an average of 2.6 minutes. The setting time controls the installation time for the grout.

4.1.1.3 Unit weight (density)

A total of 12 cylindrical specimens were tested, and the results are summarized in ***Table B-2*** of Appendix B. The grout unit weight varied from 0.51 to 0.63 g/cm^3, with an average of 0.56 g/cm^3 (***Table 4-1***). The unit weight of the grout could be used as a quality control measure in the field and also will help with the estimation of changes in weight due to leak repairs.

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

Test Completed	Number of Specimens	Range	Mean	Standard Deviation	COV(%)
Setting Time (min)	6	2.5 – 2.6	2.6	0.05	2
Unit Weight (g/cm^3)	12	0.51 – 0.63	0.56	0.03	5.4

4.1.2 Physical and mechanical properties

4.1.2.1 Water Absorbance

The water absorption test 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 4-2***. The weight change in the 3 specimens varied from 35.67% to 40.18 %, with an average of 37.57%. The volume change in the specimens varied from 23.45% to 29.47%, with a mean of 26.79%.

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	0.56			0.58			0.56		
1	0.57	16.08	14.49	0.58	16.33	15.76	0.60	14.93	7.48
2	0.58	21.26	17.43	0.60	21.83	17.81	0.62	20.60	9.66
3	0.59	27.17	20.90	0.62	29.54	21.84	0.61	28.17	18.47
4	0.59	30.50	23.94	0.62	34.68	25.66	0.62	32.89	21.19
5	0.60	33.27	25.56	0.62	37.25	27.75	0.62	34.78	22.06
6	0.60	34.57	26.62	0.63	39.27	28.79	0.62	35.92	22.96
7	0.60	35.67	27.44	0.63	40.18	29.47	0.63	36.86	23.45

4.2 Physical and Mechanical Properties

4.2.1 Shrinkage Test

A total of 3 specimens were tested for 28 days. The weight change varied from 17.62% to 28.84%, with an average value of 21.84%. The volume change varied from 15.89% to 25.39%, with an average of 19.52%. The specimens indicate that the grout swells when exposed to water in an unconfined form. The findings from the measurements are shown in ***Table 4-3***, with additional detail included in Appendix B.

Table 4-3. Results of Shrinkage Test

Sample	Weight (g)			Length (L) (mm)			Diameter (d) (mm)			Volume (V) (cm^3)			Density (D) (g/cm^3)	
	W_i	W_f	ΔW^1	L_i	L_f	ΔL^1	d_i	d_f	Δd^1	V_i	V_f	ΔV^1	D_i	D_f
1	22.7	26.7	17.62	40.33	42.37	5.06	35.8	37.6	5.03	40.6	47.05	15.89	0.56	0.57
2	21.5	27.7	28.84	37.6	40.33	7.26	35.7	38.6	8.12	37.64	47.19	25.39	0.57	0.59
3	23.6	28.1	19.07	38.03	39.97	5.10	35.5	37.5	5.63	37.04	44.15	17.28	0.63	0.64

Notes; *i* indicate initial condition.
f indicates final condition.
Δ values are in percent difference.

4.2.2 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 3 specimens over the test period of 72 hours that the gradient was applied, indicating that the permeability of the grout was zero. The results of the test are summarized in Appendix B, ***Table B-5***.

4.2.3 Compressive Strength and Stress-Strain Relationship

The compressive properties (i.e., strength, failure strain, and initial modulus) were measured over period of 30 days. A total of 17 specimens were tested, and the results are summarized in ***Table B-6*** and ***Table 4-4***. The average strength, failure stain, and initial modulus after 3 days of curing was 98 psi 60%, and 373 psi (respectively. The average strength, failure stain, and initial modulus after 28 days of curing was 101 psi 51%, and 410 psi respectively.

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

Number of Specimens	Cure Time (days)	Avg Strength (psi)/(MPa)	Avg Failure Strain (%)	Avg. Initial Modulus (psi)/(kg/cm^2)
5	3	98/0.677	55	373/26.2
8	7	99/0.683	53	396/27.8
7	28	101/0.689	51	410/28.8

4.2.4 Wet-Dry Cycles

A total of 3 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 4-5***. After the first wet-dry cycle, the average change in weight, length, diameter, and volume was 30.81%, 0.09%, 0%, and 3.27%, respectively. The unit weight and length of the specimens increased over time. After the tenth wet-dry cycle, the average change in weight, length, diameter, and volume was 41.46%,-0.62%, 0%, and 3.78%, respectively. The unit weight of the specimens also increased. The average strength of the grout after 10 wet-dry cycles was 89 psi, as summarized in Table B.7.2. The complete data sets for these tests are included in Appendix B, Tables B-7.1 and B-7.2.

Table 4-5. 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	30.81	0.09	0.00	3.27	0.60
2	41.95	-0.41	0.00	2.00	0.66
3	41.43	0.50	0.00	4.18	0.64
4	39.75	0.30	0.00	3.27	0.64
5	40.88	0.45	0.00	3.42	0.64

Cycle Number [1]	Avg ΔW [2] (%)	Avg Δ L [2] (%)	Avg Δ D [2] (%)	Avg Δ V [2] (%)	Avg Density [2] (g/cm^3)
6	40.83	0.62	0.00	5.76	0.63
7	40.89	0.52	0.00	3.68	0.64
8	40.63	0.54	0.00	3.57	0.64
9	40.82	0.56	0.00	3.66	0.64
10	41.46	0.62	0.00	3.78	0.64

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 Durability Properties

4.3.1 Chemical Resistance

A total of 9 specimens were tested over a period of 6 months, with three specimens were tested in each solution of pH 2, 7, and 10. The test results are summarized in ***Table B-8*** and ***Table 4-6***.

pH=2 solution: The weight and volume increased over the 6-month period. After 1 month, the average change in weight, volume, and unit weight was 119.25%, 23.97%, and 77.34%, respectively. After 6 months, the average change in weight, volume, and unit weight was 142.17%, 26.02%, and 92.69%, respectively.

pH = 7 (tap water): The weight and volume increased over the 6-month period. After 1 month, the average change in weight, volume, and unit weight was 126.37%, 33.63%, and 70.67%, respectively. After 6 months, the average change in weight, volume, and unit weight was 146.70%, 28.63%, and 92.00%, respectively.

pH= 10 solution: The weight and volume increased over the 6-month period. After 1 month, the average change in weight, volume, and unit weight was 83.74%, 30.48%, and 40.66%, respectively. After 6 months, the average change in weight, volume, and unit weight was 117.53%, 32.71%, and 63.76%, respectively.

Table 4-6. 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	49.3		86.86		36.71		92.38		0.54	
30	108.4	119.25	91.67	5.75	39.72	8.24	113.68	23.97	0.95	77.34
90	115.1	132.67	91.57	5.61	39.85	8.57	114.27	24.57	1.01	87.28
180	119.7	142.17	92.05	6.19	39.97	8.90	115.56	26.02	1.04	92.69
pH 7 :										
0	49.6		86.52		36.40		90.03		0.55	

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
30	112.5	126.37	97.25	7.64	39.55	8.65	119.43	32.35	0.94	70.91
90	120.4	142.51	93.24	7.79	39.65	8.95	115.08	27.98	1.04	89.68
180	122.5	146.70	93.48	8.08	39.70	9.08	115.64	28.63	1.06	92.00
pH 10 :										
0	47.5		80.85		35.89		81.71		0.58	
30	88.2	83.74	88.04	8.86	39.29	9.48	106.89	30.48	0.82	40.66
90	98.4	104.76	88.24	9.10	39.45	9.92	107.94	31.84	0.90	55.16
180	104.7	117.53	88.51	9.42	39.52	10.13	108.65	32.71	0.95	63.76

4.4 Environmental Properties – Leaching Study

A total of 3 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 for each sample to measure the leaching of chemicals from the grout. The results are reported in ***Table B-9*** of Appendix B. The TOC measured varied from 0.32 to 0.40 g/L/g of grout, with a mean of 0.35 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.

4.5 Grout/Substrate Interactions

The interaction between the grout and a concrete substrate was determined using concrete bricks, to which the grout was applied to form a sandwich that was cured for varying lengths of time to demonstrate the cure time relationship between the concrete and the grout. Four sandwich specimens were evaluated, each at 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 Type 3 (i.e., a bonding failure, where the bond between brick and grout failed). ***Figure 4-1*** shows the brick/grout specimen prior to testing, while ***Figure 4-2*** shows a typical Type 3 failure.

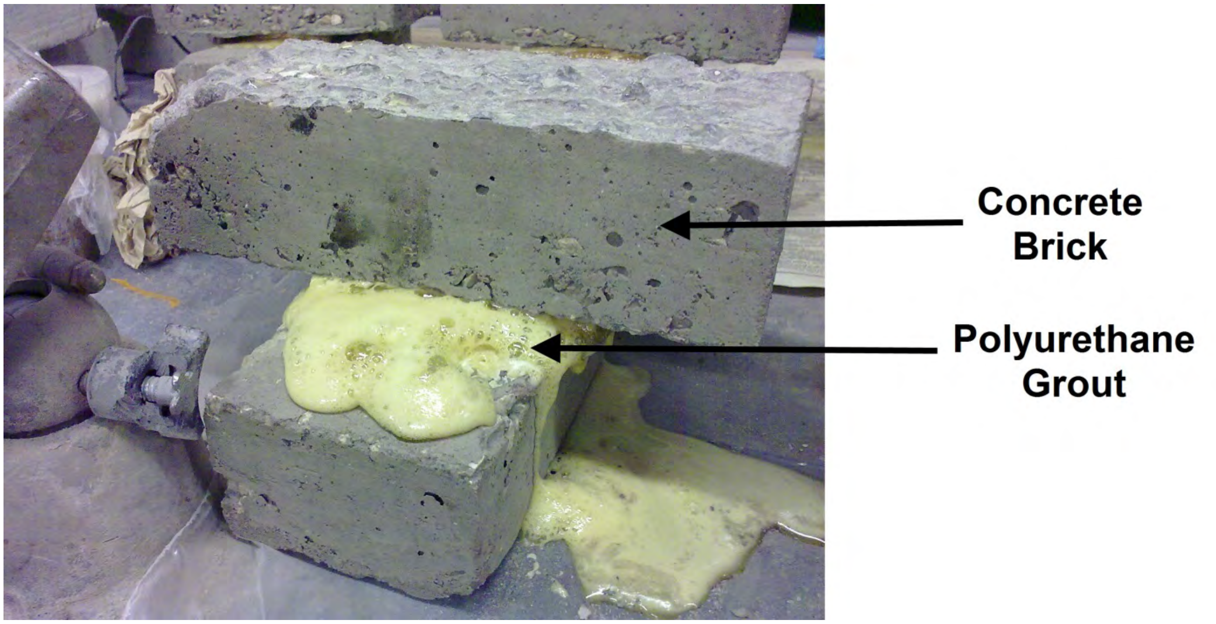
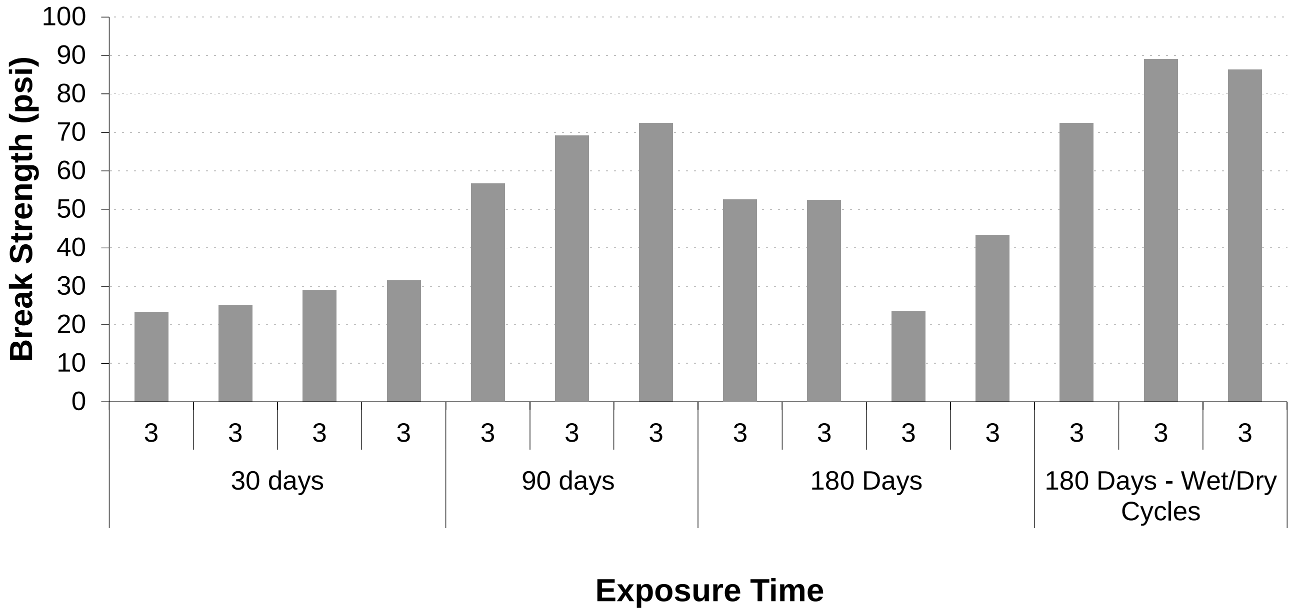


Figure 4.1. Sandwiched specimens for bonding test (SSCI GST #3).

Figure 4.2. Typical failed specimen (Type 3 failure pattern).

The results of the bonding tests are presented in ***Figure 4-3*** and ***Table 4-7***, with a more complete description of the results in Appendix C.



Note: Number at bottom indicates the type of failure.

Figure 4-3. Results of Grout-Substrate Bonding Test.

Table 4-7. Summary of Bonding Strength Tests (CIGMAT CT-3)

Exposure Time (days)	Exposure Conditions	Failure Type [1] – Number of Failures					Failure Strength (psi	
		1	2	3	4	5	Range	Average
30	Water			4			23-32	27
90	Water			3			57-72	66
180	Water			4			24-53	43
	Wet-Dry Cycles			3			72-89	83

[1] 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 crack through which all of the water would leak out. The grout was placed within the ring space (***Figure 4-4 (b)***) by the grout supplier and was allowed to cure before testing was initiated.

<u>Sample Collection</u>: Grout samples were collected at the time the grout was applied to the concrete donuts to determine the setting time and unit weight of the grout. Based on six samples tested, the setting time was determined to be 2.6 minutes. Of the 6 samples collected, the unit weight of the grout varied from 0.51 g/cm^3 to 0.59 g/cm^3, with a mean unit weight of 0.55 g/cm^3.

(a) Simulated cracked concrete.

(b) Repaired cracked concrete with grout.

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

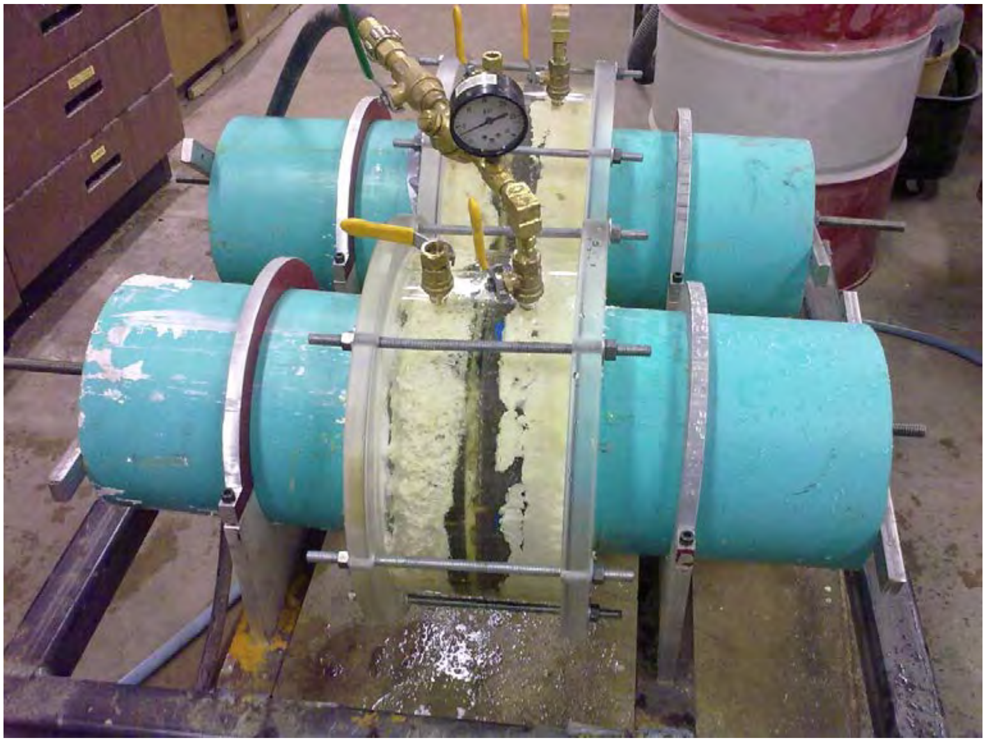


Figure 4-5. Model 4 test setup.

After the grouted joint had cured (at room conditions for at least 3 days), the joint was placed in a Plexiglass chamber (***Figure 4-5***) that was sealed to allow water to completely surround the grouted joint. Hydrostatic pressures of 3, 4, and 5 psi were applied through the inlet to the Plexiglass enclosure for 5 minutes at each pressure, and the water leaking through the grouted joint was collected and the volume recorded. After 2 wet-dry cycles, the hydrostatic pressure tests were repeated.

The results of the Model Tests are summarized in ***Table 4-8***. Model tests showed that the grouting with GST #3 was effective in significantly reducing or eliminating the leak in the cracked concrete (0 to 17.2 gallons/78.2 liters/day water leaks at 5 psi water pressure) immediately after grouting and after two wet and dry cycles over period of 1 month (0 to 13.6 gallons/61.6 liters/day water leaks at 5 psi water pressure).

Table 4-8. Model Test 4 Leak Rate Results (gallons/day)/(liters/day)

Hydrostatic Pressure	Replicate 1		Replicate 2	
	Initial Condition	Wet-Dry Cycle Condition	Initial Condition	Wet-Dry Cycle Condition
3	12.1/55	9.5/43.2	0.0	0.0
4	16.976.8	11.9/54.1	0.0	0.0
5	17.2/78.2	13.6/61.8	0.0	0.0

4.5 Summary of Observations

A combination of laboratory tests, including 2 model tests, was performed over a 6-month period on SSCI GST #3 grout to determine its effectiveness in controlling leaks:

- Model tests showed that the grouting with GST #3 grout was effective in significantly reducing or eliminating the leak in the cracked concrete (0 to 17.2 gallons/78.2 liters/day water leaks at 5 psi water pressure) immediately after grouting and after 2 wet-dry cycles over period of 1 month (0 to 13.6 gallons/61.8 liters/day water leaks at 5 psi water pressure). Prior to grouting, all of the water leaked out through the cracked concrete.
- The setting time of the grout at room temperature (21°C) varied from 2.5 to 2.6 minutes. The average unit weight of the solid grout was 0.56 g/cm^3. The average TOC in the leaching water of equal volume to the solid grout was 0.35 g/L/g of grout.
- The weight change in the specimens during the water absorption test varied from 35.67% to 40.18 %, with an average of 37.57%. The volume change in the specimens varied from 23.45% to 29.47%, with a mean of 26.79%.
- The shrinkage at 90% humidity and 23°C temperature after 28 days of testing resulted in an average weight and volume change of 21.84% and 19.52%, respectively.
- The grout was found to be impermeable under a hydraulic gradient of 100.
- The average strength, failure strain, and initial modulus after 3 days of curing was 98 psi 60%, and 373 psi respectively. The average strength, failure strain, and initial modulus after 28 days of curing was 101 psi (7.10 kg/cm^2), 51%, and 410 psi respectively.

- After the tenth wet-dry cycle, the average change in weight, length, diameter, and volume was 41.46%, 0.62%, 0%, and 3.78%, respectively. The unit weight of the specimens increased by 6.7%. The average strength of the grout after 10 wet-dry cycles was 89 psi
- The weight and volume increased over the 6-month period in all 3 pH solutions. After 6 months in a pH =2 solution (acid), the average change in unit weight and volume was 92.69% and 26.02%, respectively. After 6 months in a pH =7 solution (neutral), the average change in unit weight and volume was 92.00% and 28.63%, respectively. After 6 months in a pH =10 solution (base), the average change in unit weight and volume was 63.76% and 32.71%, respectively.
- After 6 months in water, the average bonding strength was 43 psi and all (100%) of the failures were Type 3 (bonding failure, where the bond between brick and grout failed). After 6 months of wet-dry cycle test, the average bonding strength was 83 psi and all (100%) of the failures were also Type 3.

Chapter 5
QA/QC Results and Summary

The 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. The CIGMAT Laboratories were primarily responsible for implementing the requirements of the QAPP during testing, with oversight from NSF.

The QAPP identified requirements for preparation of the concrete and clay brick specimens that would be grouted and used during the verification, along with requirements for quality control indicators (representativeness, completeness, and precision) and auditing.

5.1 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 ±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)	Strength (psi) Flexural
Concrete	138 – 149	12,700-15,800	720-960

5.1.1 Unit Weight and Pulse Velocity

The pulse velocity and unit weight were determined for 85 and 90 concrete prisms, respectively. For the concrete block specimens, the unit weight varied between 138 pcf (2,212 kg/m^3) and 149 pcf (2,388 kg/m^3), with a mean value of 143 pcf (2,292 kg/m^3). The allowable range (±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 12,700 fps (3,870 m/sec) to 15,800 fps (4,815 m/sec), with a mean of 14,015 fps (4,271 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)***).

5.1.2 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 were 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 and for the dry concrete was about 939 psi 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 Used in Test				
	Unit weight	Pulse velocity	Water absorption	Flexure*	Compression*
Concrete Prisms	90	85	None	4	None

* Flexure tests were performed for informational purposes only.

The number of specimens tested meet or exceed the VTP requirement, except for the pulse velocity for concrete cylinders and clay bricks. The unit weight of concrete is the most important parameter to determine the quality of the concrete, 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 randomly check the quality of the concrete. The pulse velocity test results on randomly selected concrete samples showed that there was nothing unusual about the concrete samples that were tested. 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 Grouting 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 6 months to determine if there are changes in bonding strength with time. Except for the 3-month water exposure, the total number of specimens for the entire test was the same as indicated in the VTP. Only 14 specimens were prepared by the Vendor for the grout/substrate evaluation, resulting in only 3 specimens for the 3-month water exposure evaluation. This does not have a significant impact on the outcome, as the results for the 3 specimens were consistent.

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	3	0
6 months	4	3

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.

In this evaluation, analysis is made using 5 different parameters. Comparison of the results for multiple specimens (minimum of 4) prepared or maintained 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. The results are shown in ***Table 5-4***.

Table 5-4. Standard Deviations for Concrete Specimens, Grout Properties and Bonding Strength

Properties	Number of Samples	Average Value	Standard Deviation
Unit weight (pcf)/(kg/m^3)	90	143/2,290	3.2
Pulse velocity (ft/sec)/(m/sec)	85	14,015/4,271	873
Setting time (min)	6	2.6	0.05
Grout compressive strength (psi)/(kg.cm^2):			
3 days cure time	5	98.3/6.9	12.4
7 days cure time	8	98.9/6.9	12.4
28 days cure time	4	100.5/7.0	8.1
Bonding strength (psi)/			
30 days water exposure	4	27	3.5
180 days water exposure	4	40	12.0

5.2.4 Accuracy

Few of the measurements made during this evaluation have references for measurement of accuracy. Analytical measurements, such as TOC, can determine accuracy using matrix spikes, from which percent recovery can be determined. No TOC matrix spike analyses were completed during this evaluation, so no determination may be made.

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.

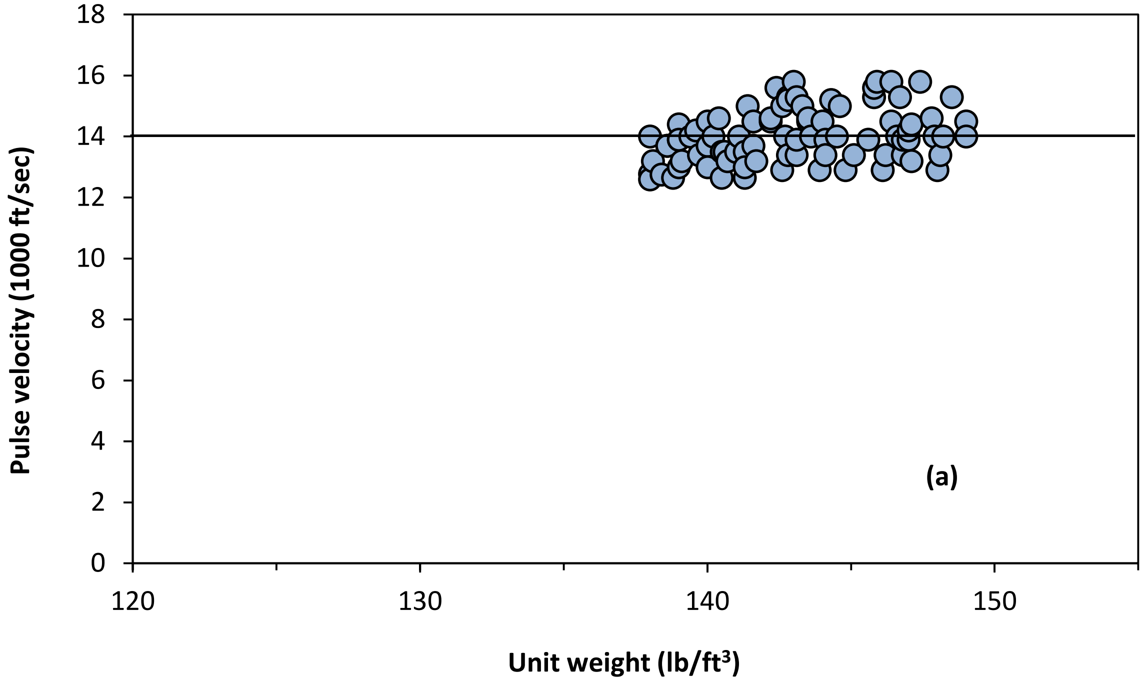
A.1 Unit Weight and Pulse Velocity

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 A-1***. The unit weight of concrete specimens varied between 138 pcf (21 kN/m^3) and 149 pcf (23 kN/m^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 A-1(b)***).

A.2 Strength

The flexural strengths of dry and wet concrete bricks are summarized in ***Table A-1***. The flexural strength of concrete bricks varied from 753 to 939 psi based on wet and dry conditions, respectively.



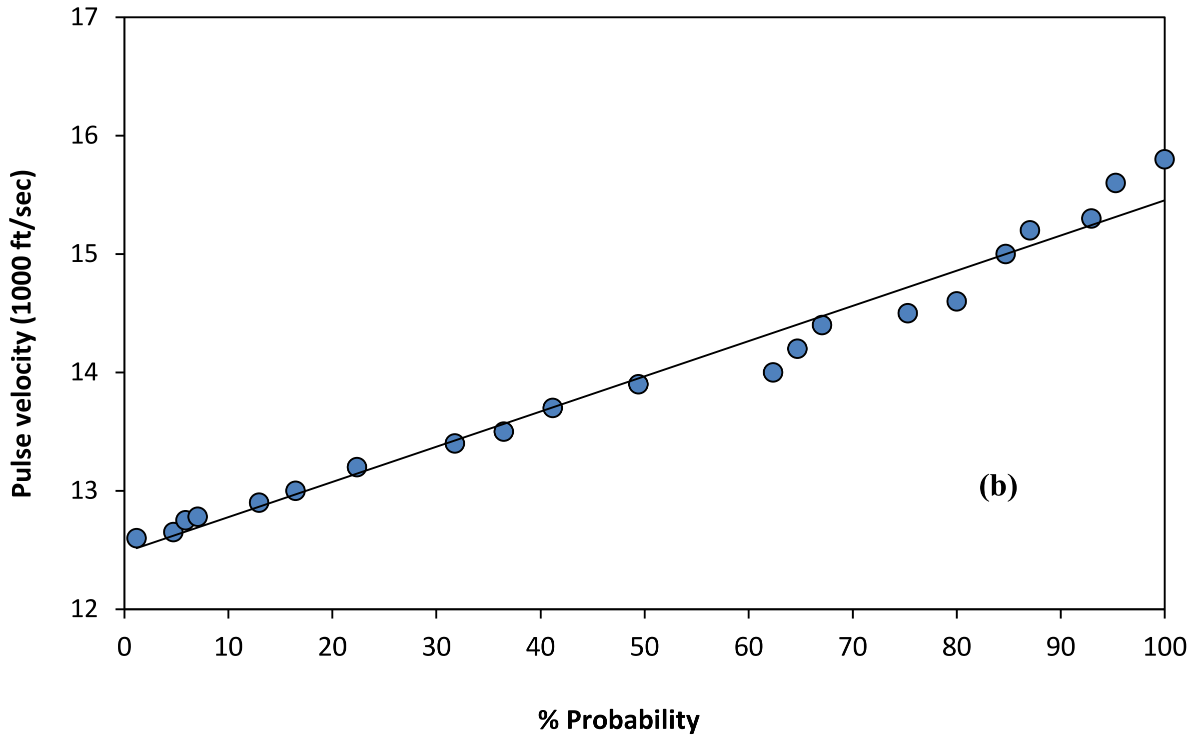


Figure A-1. Quality Control for Concrete Brick Specimens (a) Pulse Velocity Versus Unit Weight and (b) Distribution of Pulse velocity

Table A-1. Strengths of Concrete Bricks

Materials	Curing Time (days)	Compressive Strength (psi) Wet	Compressive Strength (psi) Dry	Flexural Strength (psi) Dry	Flexural Strength (psi)/(kg/cm^2) Wet
Concrete Block (No. Specimens)	28	Not Applicable	Not Applicable	939 (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
Separation Systems Consultants, Inc. GST #3

Number of Grout Specimens Tested = 59

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 resin-to-water ratio of 9:1 was used.

B.1 Viscosity

At room temperature, the grout was expanding and quickly solidifying, so the viscosity test was not performed.

B.2 Setting Time

The setting time testing was performed at room temperature and room humidity. A total of six samples were tested, and the results are summarized in ***Table B-1***. The setting time varied from 2.5 to 2.6 minutes, with an average of 2.6 minutes, and the coefficient of variation (COV) was 2%.

Table B-1. Summary of Setting Time Results.

Specimen #	1t	2t	3t	4t	5t	6t
Gelling Time (min)	2.5	2.6	2.5	2.5	2.6	2.6

B.3 Unit weight

A total of 12 cylindrical specimens were tested, and the results are summarized in ***Table B-2***. The grout unit weight varied from 0.51 to 0.63 g/cm^3, with an average of 0.56 g/cm^{3}and a COV of 5.4%.

Table B-2. Unit Weight Results for SSCI Inc. GST #3

Specimen #	Density (pcf)/(kg/m^3)
1sh	0.56/8.97
2sh	0.57/9.13
3sh	0.63/10.1
#1	0.53/8.49
#2	0.58/9.29
#3	0.54/8.65
#4	0.59/9.45
#5	0.52/8.33
#6	0.51/8.17
#7	0.59/9.45
#8	0.59/9.45
#9	0.57/9.13
Average	0.56/8.97
Standard Deviation	0.03
COV	5.4

B.4 Water Absorbance

The water absorption test 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 B-3***. The weight change in the specimens varied from 35.67% to 40.18%, with an average of 37.57%. The volume change in the specimen varied from 23.45% to 29.47%, with a mean of 26.79%.

Table B-3. Water Absorbance Results

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	0.56			0.58			0.56		
1	0.57	16.08	14.49	0.58	16.33	15.76	0.60	14.93	7.48
2	0.58	21.26	17.43	0.60	21.83	17.81	0.62	20.60	9.66
3	0.59	27.17	20.90	0.62	29.54	21.84	0.61	28.17	18.47
4	0.59	30.50	23.94	0.62	34.68	25.66	0.62	32.89	21.19
5	0.60	33.27	25.56	0.62	37.25	27.75	0.62	34.78	22.06
6	0.60	34.57	26.62	0.63	39.27	28.79	0.62	35.92	22.96
7	0.60	35.67	27.44	0.63	40.18	29.47	0.63	36.86	23.45

B.5 Shrinkage Test

A total of 3 specimens were tested for 28 days (average temperature 74°F (23°C) and relative humidity 90% to 92%). The weight change varied from 17.62% to 28.84%, with an average value of 21.84%. The volume change varied from 15.89% to 25.39%, with an average of 19.52%.

Table B-4. Shrinkage Test Results for GST #3

Specimen #		Weight (g)	Length (mm)	Diameter (mm)	Volume (cm^3)	Density (g/cm^3)
Initial	1sh	22.7	40.33	35.80	40.60	0.56
	2sh	21.5	37.60	35.70	37.64	0.57
	3sh	23.6	38.03	35.50	37.64	0.63
After 28 Days	1sh	26.7	42.37	37.60	47.05	0.57
	2sh	27.7	40.33	38.60	47.19	0.59
	3sh	28.1	39.97	37.50	44.15	0.64

		ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
After 28 Days	1sh	17.62	5.06	5.03	15.89	0.57
	2sh	28.84	7.26	8.12	25.39	0.59
	3sh	19.07	5.10	5.63	17.28	0.64
	Average	**21.84**	**5.81**	**6.26**	**19.52**	**0.60**

B.6 Permeability

Grout specimens were tested for permeability under a hydraulic gradient of 100. A total of 3 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 0.

Table B-5. Permeability Test Results

Moisture content and specimen characteristics				
Specimen		1	2	3
Average diam.	(mm)	38.10	38.10	38.10
Initial Height	(mm)	63.50	63.50	63.50
Area	(cm^2)	11.40	11.40	11.40
Total weight	(g)	40.6	39.8	40.1
Total volume	(cm^3)	72.39	72.39	72.39
Total unit weight	(g/cm^3)	0.56	0.55	0.55
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

B.7 Compressive Strength and Stress-Strain Relationship

The compressive properties (i.e., strength, failure strain, and initial modulus) were measured over period of 28 days. A total of 17 specimens were tested, and the results are summarized in ***Table B-6***. The average strength, failure stain, and initial modulus after 3 days of curing were 98 psi 60%, and 373 psi respectively. The average strength, failure stain, and initial modulus after 28 days of curing were 101 psi 51%, and 410 psi respectively.

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

Specimen	Curing time	Strength	Failure Strain	Initial Modulus
	(days)	(psi)	(%)	(psi
	3	112.6	60	390
	3	91.6	60	360
	3	102.1	60	375
	3	107.4	56	410
	3	77.6	38	330
Average		**98.3**	**55**	**373**
	7	108.3	46	450/31.6
	7	80.5	37	410/28.8
	7	96/	58	380/31.6
	7	112.8/7.9	55	440//39.9
	7	89.4/6.3	54	400/28.1
	7	84.5/5.9	55	350/24.6
	7	116/8.2	60	390/27.4
	7	103.5/7.3	60	350/24.6
Average		**98.9/7.0**	**53**	**396/27.8**
	28	92.4/6.5	48	420/29.5
	28	113/7.9	54	400/28.1
	28	102.3/7.2	50	430/30.2
	28	94.2/6.6	52	390/27.4
Average		**100.5/7.1**	**51**	**410/28.8**

B.7. Wet-Dry Cycles

A total of 3 specimens were tested for 10 cycles. The cycles started with a wet cycle first. The changes in weight, length, diameter, and volume are reported in ***Tables B-7.1 and B-7.2***. After the first wet-dry cycle, the average change in weight, length, diameter, and volume was 30.81%, 0.09%, 0%, and 3.27%, respectively. The unit weight of the specimens increased. After the tenth wet-dry cycle, the average change in weight, length, diameter, and volume was 41.46%, 0.62%, 0%, and 3.78%, respectively. The unit weight of the specimens increased by 0.99%. The average strength of the grout after 10 wet-dry cycles was 89 psi (6.26 kg/cm^2).

Table B-7.1. Wet-Dry Cycle Test Results for SSCI GST #3

	Specimen #	Weight (g)	Length (mm)	Diameter (mm)	Volume (cm^3)	Density (g/cm^3)
Original	#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

	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
Cycle 1	#18	35.70	-0.81	0.00	-0.46	0.61
	#19	35.18	-0.07	0.00	6.81	0.61
	#20	21.56	1.17	0.00	3.46	0.57
	Average	30.81	0.09	0.00	3.27	0.60

	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
Cycle 2	#18	46.64	-1.02	0.00	-1.02	0.67
	#19	60.80	-0.14	0.00	6.73	0.73
	#20	18.40	-0.07	0.00	0.29	0.57
	Average	41.95	-0.41	0.00	2.00	0.66

	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
Cycle 3	#18	38.96	-1.05	0.00	-0.02	0.63
	#19	59.85	1.03	0.00	8.54	0.71
	#20	25.46	1.52	0.00	4.03	0.58
	Average	41.43	0.50	0.00	4.18	0.64

	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
Cycle 4	#18	34.55	-0.99	0.00	-0.48	0.61
	#19	57.55	0.95	0.00	8.46	0.70
	#20	27.14	0.93	0.00	1.83	0.60
	Average	39.75	0.30	0.00	3.27	0.64

	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
Cycle 5	#18	38.39	-1.02	0.00	-0.30	0.63
	#19	55.64	1.09	0.00	8.77	0.69
	#20	28.62	1.27	0.00	1.80	0.61
	Average	40.88	0.45	0.00	3.42	0.64

	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
Cycle 6	#18	36.66	-0.95	0.00	-0.08	0.62
	#19	57.93	1.23	0.00	8.92	0.70
	#20	27.88	1.58	0.00	8.45	0.57
	Average	40.83	0.62	0.00	5.76	0.63

	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
Cycle 7	#18	37.81	-0.92	0.00	-0.04	0.62
	#19	56.79	1.16	0.00	9.07	0.70
	#20	28.07	1.31	0.00	2.00	0.61
	Average	40.89	0.52	0.00	3.68	0.64

	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
Cycle 8	#18	37.43	-0.85	0.00	0.18	0.62
	#19	56.02	1.13	0.00	8.81	0.70
	#20	28.44	1.34	0.00	1.71	0.61
	Average	40.63	0.54	0.00	3.57	0.64

	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
Cycle 9	#18	38.39	-0.89	0.00	-0.01	0.62
	#19	55.45	1.19	0.00	9.10	0.69
	#20	28.62	1.37	0.00	1.90	0.61
	Average	40.82	0.56	0.00	3.66	0.64

	Specimen #	ΔW (%)	ΔL (%)	ΔD (%)	ΔV (%)	Density (g/cm^3)
Cycle 10	#18	38.96	-0.81	0.00	0.21	0.62
	#19	56.41	1.23	0.00	9.15	0.70
	#20	29.00	1.44	0.00	1.98	0.61
	Average	41.46	0.62	0.00	3.78	0.64

Table B.7.2 – Compressive Strength after wet-dry cycles for SSCI GST #3

Specimen #	Compressive Strength (psi)/(kg/cm^2)
#18	86/6.0
#19	94/6.6
#20	87/6.1
Average	89/6.2

(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 119.25%, 23.97%, and 77.34%, respectively. After 6 months, the average change in weight, volume, and unit weight was 142.17%, 26.02%, and 92.69%, respectively. The weight and volume increased over the 6-month period.

pH = 7 –tap water: After 1 month, the average change in weight, volume, and unit weight was 126.37%, 33.63%, and 70.67%, respectively. After 6 months, the average change in weight, volume, and unit weight was 146.70%, 28.63%, and 92.00%, respectively. The weight and volume increased over the 6-month period.

pH = 10 solution: After 1 month, the average change in weight, volume, and unit weight was 83.74%, 30.48%, and 40.66%, respectively. After 6 months, the average change in weight, volume, and unit weight was 117.53%, 32.71%, and 63.76%, respectively. The weight and volume 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)	#4	41.4	69.97	35.83	70.55	0.59
	#5	53.3	95.80	36.87	102.28	0.52
	#6	53.3	94.80	37.43	104.31	0.51
	Average	49.33	86.86	36.71	92.38	0.54
30 days (pH=2)	#4	88.3	75.50	39.57	92.85	0.95
	#5	119.0	100.37	39.77	124.68	0.95
	#6	117.9	99.13	39.83	123.51	0.95
	Average	108.4	91.67	39.72	113.68	0.95
	% Change	119.25	5.75	8.24	23.97	77.34
3 months (pH=2)	#4	93.0	75.27	39.67	93.03	1.00
	#5	126.5	100.40	39.80	124.91	1.01
	#6	125.8	99.03	40.07	124.88	1.01
	Average	115.1	91.57	39.85	114.27	1.01
	% Change	132.67	5.61	8.57	24.57	87.28
6 months (pH=2)	#4	97.5	75.87	39.80	94.39	1.03
	#5	131.5	100.67	39.93	126.06	1.04
	#6	130.2	99.60	40.17	126.23	1.03
	Average	119.7	92.05	39.97	115.56	1.04
	% Change	142.17	6.19	8.90	26.02	92.69

	Specimen #	Weight (g)	Length (mm)	Diameter (mm)	Volume (cm^3)	Density (g/cm^3)
Original (pH=7)	#1	53.1	94.17	36.83	100.32	0.53
	#2	52.7	90.40	35.80	91.00	0.58
	#3	42.9	75.00	36.57	78.78	0.54
	Average	49.57	86.52	36.40	90.03	0.55
30 days (pH=7)	#1	123.0	99.77	39.67	123.31	1.00
	#2	121.2	98.67	39.20	119.08	1.02
	#3	93.3	93.30	39.77	115.90	0.81
	Average	112.5	97.25	39.55	119.43	0.94
	% Change	126.37	12.40	8.65	32.35	70.91

3 months (pH=7)	#1	131.5	99.87	39.73	123.81	1.06
	#2	128.7	98.87	39.40	120.54	1.07
	#3	101.1	80.97	39.83	100.89	1.00
	Average	120.4	93.24	39.65	115.08	1.04
	% Change	142.51	7.79	8.95	27.98	89.68
6 months (pH=7)	#1	133.5	100.10	39.77	124.35	1.07
	#2	130.4	99.00	39.43	120.89	1.08
	#3	103.5	81.33	39.90	101.69	1.02
	Average	122.5	93.48	39.70	115.64	1.06
	% Change	146.70	8.08	9.08	28.63	92.73

	Specimen #	Weight (g)	Length (mm)	Diameter (mm)	Volume (cm^3)	Density (g/cm^3)
Original (pH=10)	#7	37.0	62.10	36.00	63.21	0.59
	#8	53.0	90.57	35.63	90.30	0.59
	#9	52.4	89.87	36.03	91.63	0.57
	Average	47.47	80.85	35.89	81.71	0.58
30 days (pH=10)	#7	61.1	67.37	39.03	80.60	0.76
	#8	105.9	98.93	39.33	120.19	0.88
	#9	97.6	97.83	39.50	119.88	0.81
	Average	88.2	88.04	39.29	106.89	0.82
	% Change	83.74	8.86	9.48	30.48	40.66
3 months (pH=10)	#7	67.1	67.50	39.30	81.88	0.82
	#8	118.2	99.23	39.47	121.41	0.97
	#9	110.0	98.00	39.57	120.52	0.91
	Average	98.4	88.24	39.45	107.94	0.90
	% Change	104.76	9.10	9.92	31.84	55.16
6 months (pH=10)	#7	70.6	67.63	39.40	82.46	0.86
	#8	125.9	99.33	39.43	121.29	1.04
	#9	117.5	98.57	39.73	122.20	0.96
	Average	104.7	88.51	39.52	108.65	0.95
	% Change	117.53	9.42	10.13	32.71	63.76

(j) Leaching study

A total of 3 specimens were tested in equal volume of water, and TOC values are reported in ***Table B-9***. The TOC measured varied from 0.32 to 0.40 g/L/g of grout, with a mean of

0.35 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 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	0.03	
2	Grout	33.8	60	60	10.65	0.32
3	Grout	34.5	60	60	13.95	0.40
4	Grout	34.1	60	60	11.48	0.34
Average						0.35

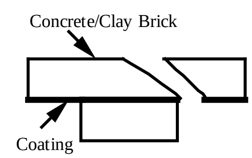
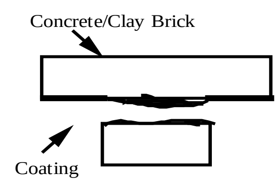
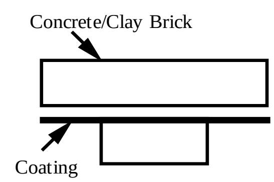
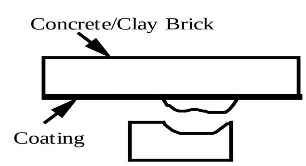
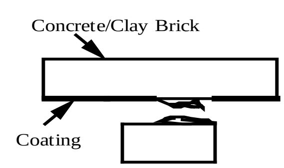
Appendix C

GROUT-SUBSTRATE (CONCRETE) INTERACTION

Number of Tests = 14

A total of 15 sandwiched bonding tests (CIGMAT CT-3) were performed after 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	
Type 2	Coating Failure	
Type 3	Bonding Failure	
Type 4	Bonding and Substrate Failure	
Type 5	Bonding and Coating Failure	

(a) After 1 month

A total of 4 specimens were tested. The results are summarized in ***Table C-2***. Based on the test results, 100% of the failures were Type 3. The bonding strength varied from 23 to 32 psi (1.62 to 2.25 kg/cm^2). The average strength measured was 27 psi (1.90 kg/cm^2).

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			23/1.62
2	30			X			25/1.76
3	30			X			29/2.04
4	30			X			32//2.25
Total No. (% Failure)				4 (100%)			4 successful tests.
Remarks	Up to 1 month						Type 3 failure observed.

(b) 3 months

Since the bonding strength results were close, and the mode of failure was the same, it was determined that testing 3 specimens would be adequate. The results are summarized in ***Table C-3***. Based on the test results, 100% of the failures were Type 3. The bonding strength varied from 57 to 72 psi (4.00 to 5.06 kg/cm^2). The average strength measured was 66 psi (4.64 kg/cm^2).

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			57/4.00
6	90			X			69/4.85
7	90			X			72/5.06
Total No. (% Failure)				3 (100%)			3 successful tests.
Remarks	Up to 3 months						Type 3 failure observed.

(c) 6 months

A total of 4 specimens were tested. The results are summarized in ***Table C-4***. Based on the test results, 100% of the failures were Type 3. The bonding strength varied from 24 to 53 psi (1.69 to 3.73 kg/cm^2). The average strength measured was 43 psi (3.02 kg/cm^2).

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	
11	180			X			53/3.73
12	180			X			53/3.73
13	180			X			24/1.69
14	180			X			43/3.02
Total No. (% Failure)				4 (100%)			4 successful tests.
Remarks	Up to 6 months						Type 3 failure observed.

(d) 6 months (Wet-Dry)

A total of 3 specimens were tested. The results are summarized in ***Table C-5***. Based on the test results, 100% of the failures were Type 3. The bonding strength varied from 72 to 89 psi (5.06 to 6.26 kg/cm^2). The average strength measured was 83 psi (5.83 kg/cm^2).

Table C-5. Summary of 6-months 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	
8	180			X			72/5.06
9	180			X			896.26
10	180			X			86/6.05
Total No. (% Failure)				3 (100%)			3 successful tests.
Remarks	Up to 6 months (wet-dry)						Type 3 failure observed.

Appendix D

Grout Vendor Data Sheet

GROUT VENDOR DATA SHEET

Grout Product Name: GST #3

Grout Product Manufacturer Name and Address: SSCI Environmental, Inc.

17041 El Camino Real, Ste. 200; Houston, TX 77058

Grout Type: Polyurethane

Chemical Formula: Dioocyanate, oligomers of diiocyanate

TESTING METHOD	MANUFACTURER'S RESULTS
Type of Resin, Initiator and/or Promotor	Strong flexible foam, grey color
Grout Mix (by weigh or volume)	Water / various ratios
Resin Viscosity (ASTM __________)	2200 – 2500 cps
Flash Point (ASTM D 93/ __________)	200º F
Tensile Adhesion to Concrete and Clay Brick (ASTM _________)	≈ 20 psi
Chemical Resistance (ASTM ___________) (NaOH, 3% H_2SO_4 or others)	Bases = Nominal impact; Sulfuric acid = Mild discoloration
Volatile Organic Compounds – VOCs (ASTM _____________)	Does not apply

WORKER SAFETY	RESULT/REQUIREMENT
Flammability Rating	Not Applicable
Known Carcinogenic Content	TDI
Other Hazards (Corrosive)	None
MSDS Sheet Availability	Yes

ENVIRONMENTAL CHARACTERISTICS	RESULT/REQUIREMENT
Heavy Metal Content (w/w)	None
Leaching from Cured Grouts	None
Disposal of Cured Grouts	Cured material is non-hazardous

DATA SHEET ON PROPERTIES OF GROUT (Continued)

APPLICATION CHARACTERISTICS	RESULT/REQUIREMENTS
Minimum Application Temperature	40º F
Maximum Application Temperature	120º F
Minimum Cure Time before Immersion into Service	Water is catalyst
Type of Preparation Before Grouting	Clean surface before application
Grouting Pressure	Not applicable

VENDOR EXPERIENCE	COMMENTS
Length of Time the Grout in Use	20+ years
Applicator Training and Qualification Program	Field and classroom training
QA/QC Program for Grouts in the Field	Verify product being used

ADDITIONAL COMMENTS (Including Case Studies on Performance)