CIGMAT Test Protocol for Evaluating Grout Materials to Repair Water Leaks in Concrete Pipes

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ABSTRACT

Grouts are being used in the rehabilitation of various pipelines particularly for leak control in cracked concrete infrastructures including all types of wastewater and storm water pipelines. Hence there was a need to develop test protocols to evaluate the performance of various types of grouts based on their applications. The aim of the controlled testing program, approved by the EPA was to evaluate the performance of grouting materials used in the rehabilitation of cracked concrete structures, including pipes, to quantify the infiltration using a combination of model and laboratory tests at the Center for Innovative Grouting Materials and Technology (CIGMAT). A combination of grout and grout-substrate bonding with a simulated model test are being used to evaluate grouts for leak control at repaired cracks in concrete. Grouts are being characterized using the working, physical, mechanical and durability properties. To quantify the grout properties several ASTM and CIGMAT test methods are being used. The concrete crack repairs were simulated using concrete rings placed at selected distance apart. Grouted cracks are being tested to 34 kPa (5 psi) water pressure, after subjecting the repaired joints to wet-dry cycles, to quantify the effective reduction in water infiltration. Test results of a polyurethane grout was used develop a new parameter to define leakage in the repaired joint. The controlled verification test program approved by the EPA will be of assistance to manufacturers, suppliers, engineers and owners in evaluating the grouts used for cracked concrete repairs.

INTRODUCTION

One of the very critical issues facing the nation today involves leaking concrete pipelines and structures causing increased pollution of waterways, shorelines, rivers, bays and streams. Several types of grout materials have been used in controlling leaks in concrete wastewater systems and storm systems [Vipulanandan, 1996b]. These grout materials have been commonly used for leak control in below grade wet wells or holding tanks; manholes; sewer and storm lines, cracked retaining walls and other underground structures [Karol, 1990, Vipulanandan, 1996a, Vipulanandan, 2000; Ozurel et al. 2004]. Many owners are discovering that if water and wastewater leaking problems are not controlled it will lead to frequent overflows and undue burden on the treatment facilities.

The primary goal of grouting these facilities is to return the structure to its original working conditions by the oldest trenchless technology method, in-situ grouting (Krizek et al. 1985 and Vipulanandan et al 1996-2009). Use of grouts to control leaks in wastewater facilities and other leaking structures is one method currently being adopted, but there is no systematic method for evaluating the performance of these grouts under service conditions. The aim of this document is to describe a testing protocol developed to evaluate grout materials through a combination of full scale and laboratory tests for applications in the rehabilitation and new construction of wastewater facilities.

Wastewater facilities are wet and experience hydrostatic pressure under normal service conditions. Application of grouts to leaking concrete cracks is considered a challenge and must be evaluated. Bonding between the concrete surface and the grouting material is another factor that must be evaluated to determine the performance. Chemical resistance of grouts and grout modified materials to the sewer corrosive environment is also very important. To select the proper grouting material to solve the leaking problems, their performance and installation requirements must be well understood. Restoring leaking joints and cracks in concrete structures requires considering grouted soil mass around the joints and grout behavior within leaking cracks.

Since several factors in the field can affect the performance of grouting, it is necessary to identify these important factors through controlled experiments where variables are studied one at a time. In this document, a comprehensive testing program is described that was developed for evaluating grouting for leak control applications.

Objectives

The overall objective was to develop a testing program to systematically evaluate grouts for control of leaks in concrete structures. Specific objectives are as follows: (a) to evaluate the working, physical, mechanical and durability properties of grouts (2) to characterize the grout-substrate interaction and durability and (3) to verify the performance of repaired concrete cracks under dry and wet cycles and hydrostatic pressure 34 kPa (5 psi, 10 ft of water) using model tests over a period of one month.

Testing will be done using the relevant ASTM (2010) and CIGMAT standards.

TESTING PROGRAM

Experimental Approach

The verification plan includes material characterization and model tests. Material characterization includes testing of grouts, grouted soil and grout-concrete interaction. The model test includes grouting of joints with and without infiltration and then testing for leakage rate (EPA/ETV (2004); (http://nsdi.epa.gov/**etv**/pubs/600r04183.pdf)).

(i) Grout Tests

ASTM Standard Method C31/C-31M-96 shall be used for making and curing test specimens for cement, acrylic, or acrylamide-based grouts (which typically do not expand while curing). Standard Practice CIGMAT GR 4-00 shall be used for making and curing test specimens for polyurethane-based grout (which may expand while curing). Specimens to be cured under water shall be completely submerged in a water bath of tap water at room temperature. If the specimens float, a small amount of force will be applied keep the specimen submerged. Multiple specimens of the same type of grout or grouted sand material may be placed in the same water bath. After solidification, specimens shall be removed from the mold and stored in sealed plastic bags in a temperature and humidity controlled room at 23 ± 2°C (room temperature) and 50 ± 5 percent humidity.

Grout properties to be tested can be grouped as follows:
(1) Working properties
(2) Physical and mechanical properties
(3) Durability properties
(4) Leachability

Table 1. Grout Tests for Various Applications

Properties	Tests	Conditions	Test Method to be Used
Working Properties	Viscosity	23ºC	CIGMAT GR 6-02
	Setting (Gel) Time	23ºC	ASTM C 191 (cement-based) or EPA/ETV (2004) (polymer-based)
Physical and Mechanical Properties	Unit Weight	23ºC	CIGMAT GR 1-00
	Water Absorption	23ºC	CIGMAT GR 3-00
	Shrinkage	Temp, humidity	EPA/ETV 2004
	Permeability	Water	CIGMAT GR 7-02
	Compressive Strength	3, 7, 28 days	CIGMAT GR 2-02
	Tensile Strength	3, 7, 28 days	CIGMAT PC 2-99 (Specimen preparation by CIGMAT CH 2-01)
	Elongation	3, 7, 28 days	CIGMAT PC 2-99 (Specimen preparation by CIGMAT CH 2-01)
Durability Properties	Wet-Dry Cycle	Number of cycles	CIGMAT GR 3-00
	Chemical Resistance	pH = 2, 7, 10	CIGMAT CH 2-01
Environment. Properties	Leaching	Water	EPA/ETV (2004)

(ii) Grout-Substrate Interaction

Interaction between the grout and a concrete substrate must be 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 shall be conducted over a period of six (6) months in accordance with CIGMAT GR 5-00 (where two cylinders are bonded with grout) or CIGMAT CT 3-00 (where the area between concrete bricks/prisms is grouted), as selected by the vendor prior to the ETV verification. In addition, bonded configurations prepared according to either CIGMAT GR 5-00 or CIGMAT CT 3-00 will be subjected to wet-dry cycle testing.

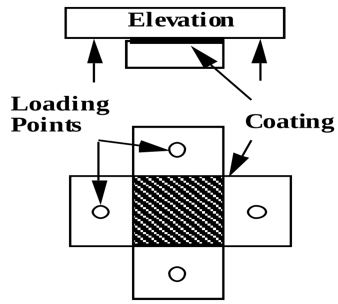


Figure 1 - Laboratory Bonding Test Configuration (CIGMAT CT-3)

Table 2. Grouted Sand and Grout-Substrate Interaction Tests

Materials	Tests	Conditions	Test Method to be Used
GROUTED SAND			
Physical and Mechanical Properties	Unit weight	Cured	CIGMAT GR 1-00
	Water Absorbance	23^oC	CIGMAT GR 3-00
	Shrinkage	Temp, humidity	EPA/ETV (2004)
	Permeability	Water	CIGMAT GR 7-02
	Compressive Strength	3, 7, 28 days	CIGMAT GR 2-02
	Tensile Strength	3, 7, 28 days	CIGMAT PC 2-99
Durability Properties	Wet-Dry Cycle	Number of Cycles	CIGMAT GR 3-00
	Chemical Resistance	pH = 2, 7,10	CIGMAT CH 2-01
GROUT-SUBSTRATE INTERACTION			
Bonding Strength	Wet Condition	Concrete, clay brick, cured under water	CIGMAT GR 5-00 or CIGMAT CT 3-00
	Wet-dry cycle	Number of cycles	CIGMAT GR 3-00

(a) Cylinder Bonding (CIGMAT GR 5-00)

This test configuration may be used in determining the bonding strength of various grout materials (Vipulanandan et al. 1986). The test consists of sandwiching a layer of grout between flat surfaces of concrete (the ends of concrete cylinders), and then loading the test specimen in tension. Details of preparing the specimens are in CIGMAT GR 5-00.

(b) Brick/Prism Bonding (CIGMAT CT 3-00)

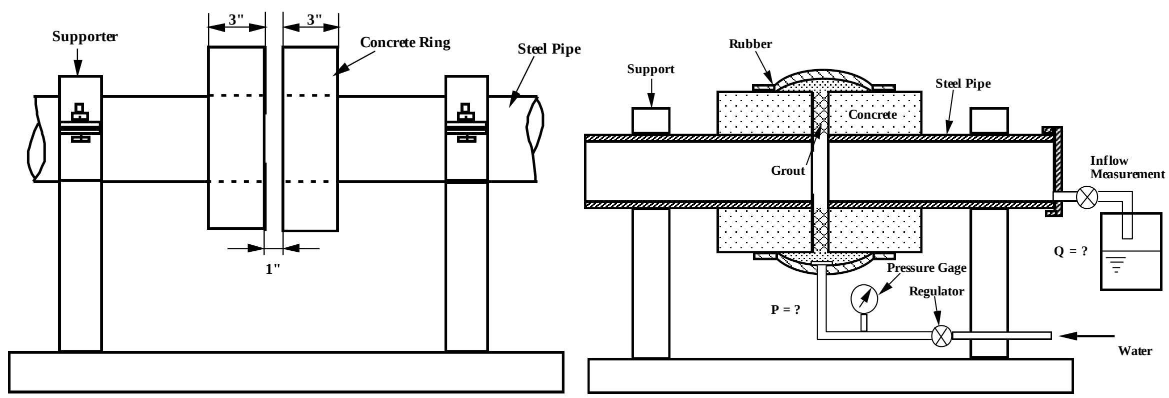
Although CIGMAT CT 3-00 was developed for coating materials, it may be adopted for grouts. In CIGMAT CT 3-00, the grout shall be sandwiched between a pair of rectangular concrete block and clay brick specimens and then tested for bonding strength and type of failure. Wet specimens shall be used to simulate extreme grouting conditions. The bonded wet specimens shall be immersed in water up to the point of testing. The reported data shall include the brick used, number of specimens tested, age of specimen at time of test, average bond strength, standard deviation, type of failure and the bond strength.

(c) Wet-Dry Cycle

During its service life, a grouted concrete joint could be subjected to number of wet-dry cycles. Hence each bonded configuration will be tested for performance by subjecting it to 10 wet and dry cycles, where one wet-dry cycle takes 14 days, for a total test time of 140 days, or until failure.

(iv) Model Tests (EPA/ETV (2004))

Since water leaks can occur under different conditions, the model test must simulate the field condition.



(a) Model Test - Concrete Leak Repair (b) Hydrostatic Test on the Repaired Model

Figure 2 - Model Tests for Leak Control

Model Test: Concrete Leak Repair

In order to simulate a leak in a concrete structure, this model test (Figure 2(d)) shall use 10 in (250 mm) diameter circular concrete disks with 6 in (15 cm) openings at the center (so that each disk is donut shaped). As a default, the two disks shall be placed an inch (25 mm) apart and grouted by the vendor. The vendor may, however, select the opening size. The grouted joint shall be subjected to hydrostatic pressure testing to determine the leak rate.

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

- The gap between the concrete rings on the testing rig shall be set at the appropriate dimension, as specified by the Vendor.

- The vendor or CIGMAT shall apply the grout in the gap in accordance with the vendor's standard procedures.

Model Test Procedures

Each model test shall be conducted in duplicate. Prior to grouting, each of the joints to be tested during model testing shall be calibrated in order to develop a characteristic leak rate versus pressure relationship. The grout shall be applied to wet concrete disks (Model) by the vendor. CIGMAT personnel shall supervise the grouting procedures and pictures shall be taken of the joint/concrete disks prior to and after grouting. The time elapsed and volume of grout used during the grouting process shall be recorded. The time period following the application of the grout before testing is initiated shall be determined from the manufacturer's literature and is dependent on the penetrability and setting time of grout. During the grouting of the joints/cracks, at least ten (10) grout samples shall be collected for testing the setting time, unit weight and compressive properties of the grouts.

Once the grouted joint(s)/concrete disks have cured per the manufacturer's literature, they shall be subjected to the following regimen:

1. Apply hydrostatic pressure of 3 psi (21 kPa) and hold for 5 minutes; then measure the leak rate using a graduated cylinder and a stop watch.
2. Repeat step (1) at a hydrostatic pressure of 4 psi (28 kPa).
3. Repeat step (1) at a hydrostatic pressure of 5 psi (34 kPa).
4. Maintain saturated conditions for a period of one week. For Model Tests 1,2 and 3, the chambers will be completely filled with water with no hydrostatic pressure. In Model Test 4 the joint will be soaked in water.
5. Drain all water from the chambers and allow them to stand for one week. Under drained conditions, the water will be completely drained from the test chamber.
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 shall include the characteristic leak rate versus pressure for each ungrouted joint, lapsed time and volume of grout used during the grouting process, lapsed time between grouting and commencement of testing, data for grout (setting time, unit weight and compressive properties), initial leak rates at the three hydrostatic pressures, and the leak rates at the three hydrostatic pressures following the saturated-drained cycles. Based on the test results, the grouting may be classified as low durability (up to 25 percent reduction in infiltration), medium durability (25-50 percent reduction in infiltration) and high durability (>50 percent reduction in infiltration).

Model Test Analyses

Model tests showed that the grouting with polyurethane grout was effective in eliminating the leak (over 1500 gallons/day) in the cracked concrete to zero to 17.2 gallons/day water leaks at 5 psi water pressure immediately after grouting. After two wet and dry cycles over a period of one month the leakage rate was zero to 13.6 gallons/day at 5 psi water pressure.

Model test was idealized as shown in Figure 3. Grout and concrete assumed to be impervious and leaking took place in grout and concrete interface. K_2 is the hydraulic conductivity at the interface. The thickness of the interface cannot be estimated so a new parameter was defined called K_2t. By considering the leak at the joint and applying the Darcy's Law results in the following relationship;

$$K_2t = Q\rho gd/(2\pi rP) \quad \ldots\ldots(1)$$

Where Q is the rate of water leak, t is the thickness of the interface. K_2t = hydraulic conductivity (m/s) * thickness (m) (m^2/s)

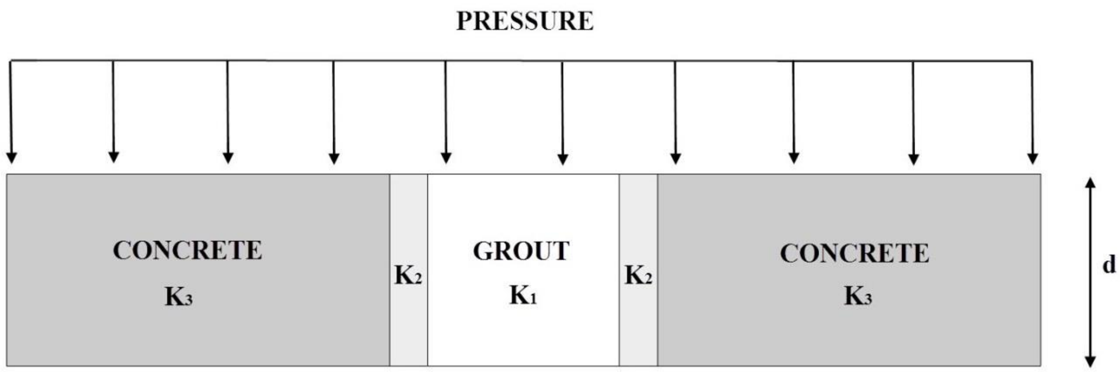


Figure 3. Model test – materials and hydraulic conductivities

The data points and estimated lines for different $K_2.t$ values for the polyurethane grout are shown in Fig. 4. Leak rates were between K_2t values of 1×10^{-8} and 2×10^{-8} m^2/s and leak rates were decreased after the wet-dry cycles. Since concrete and grout was assumed to be impervious, leakage was taking place through the grout-concrete interface. Leak rate depends on the hydraulic conductivity and thickness of interface. K.t parameter includes two unknowns together and defines a new parameter.

CONCLUSIONS

There are no standard (ASTM) methods to evaluate the performance of grouts for various infrastructure rehabilitations. CIGMAT is an EPA approved facility for testing the grouts under various applications.

(1) Grouts can be tested to evaluate the effectiveness for leakage control in concrete facilities. Based on the grout application condition (dry or wet), appropriate grout, grout-substrate interaction and model tests will be used. Based on the grout application between 48 and 72 grout tests and 24 grout-substrate interaction tests are performed in addition to the Model test selected for the application. Testing will be done over period of six months.

(2) A model has been developed to represent potential leakage in repaired cracks.

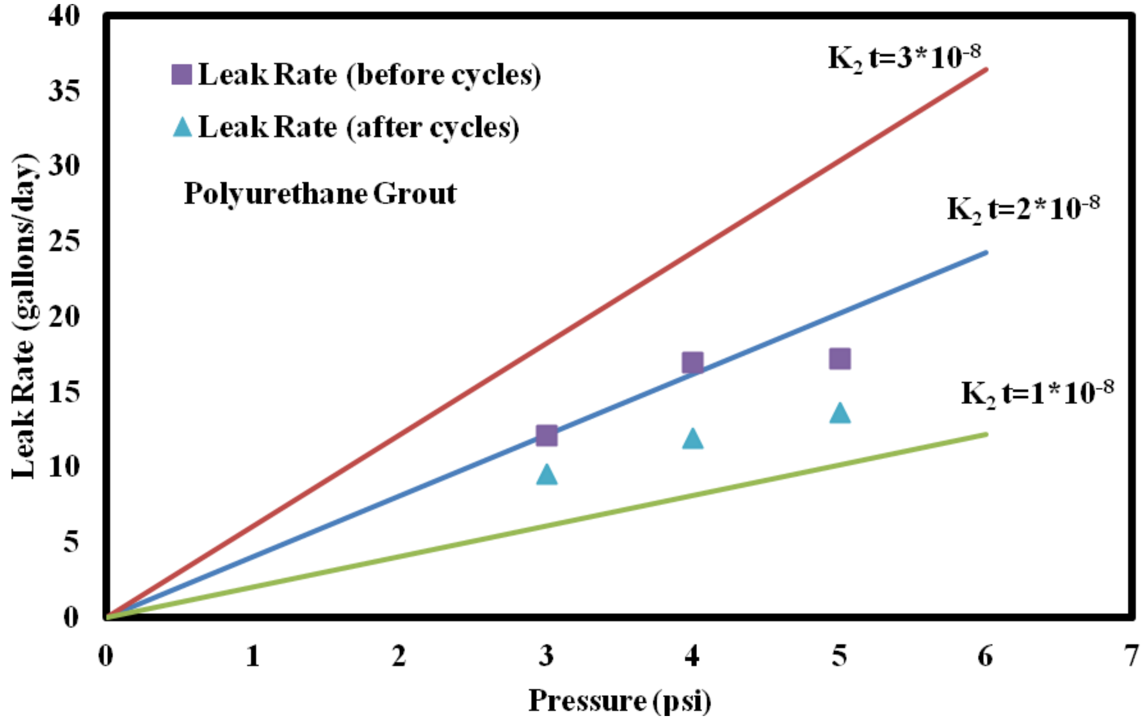


Figure 4. Predicted leak rate lines for different K_2t values – Polyurethane Grout

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