

TWO DIMENSIONAL MODEL STUDY ON INFILTRATION CONTROL AT A LATERAL PIPE JOINT USING ACRYLAMIDE GROUT

H. Gurkan Ozgurel¹, H. A. González² and
C. Vipulanandan³, Member, ASCE

ABSTRACT

One of the challenges faced in maintaining the aging sewer systems is the infiltration, which is caused by the deterioration of the sewer systems. In this study, A table top lateral joint model was used to investigate grout movement through soil, when sealing sewer pipe leaks at lateral joints by grouting. Acrylamide chemical grout was injected through a leaking lateral joint into a coarse sand ($d_{10}=0.5$ mm), using 3 psi (21 kPa). The volume of infiltration was measured before and after grouting to determine the effectiveness of grouting. The volume infiltration was measured at 1 min, 1 hr and 24 hrs. after grouting using an external water pressure up to 3 psi (21kPa). At the end of the test, the shape of the grout bulb around the joint was mapped. A mathematical model was developed to determine the shape of the grouted region around the lateral joint, and verified with the experimental data. The amount of grout used to control the leak around the joint was compared to the recommendation of ASTM F 2304

INTRODUCTION

Infiltration is caused by rain water and/or groundwater that enter through the defects in the sewer systems. Infiltration reduces the effective capacity of a sewer system by adding extra flow and by depositing fine particles inside the systems. Number of factors such as root penetration, ground movement, joint displacement, construction flaws, and unsealed connections lead to infiltration [CIRIA, 1997]. Infiltration increases the cost of treating wastewater, adds to the flooding problems and sanitary sewer overflows (SSO).

¹ M.S.C.E., E.I.T, Staff geotechnical engineer at URS Corp. gurkan_ozgurel@urscorp.com

² M.S.C.E. Student, Dept. of Civil and Environmental Engng. Univ. of Houston, Houston, Tx, Grad. Asstnt Cntr for Innovative Grouting Mat. And Technol. (CIGMAT)

³ Chairman, Prof. Dept. of Civil. and Environ. Engng., Univ. of Houston, Houston, Tx, and Dir. of Cntr for Innovative Grouting Mat. and Technol. (CIGMAT), 77204-4003, (phone # (713) 743 4278; Fax (713)743 4260 email: cvipulanandan@uh.edu)

Today the federal regulations on the waste water systems are more stringent. USEPA, in conjunction with municipal and other industry representatives, have developed a framework for a dynamic management approach for collection systems called the capacity, management, operation, and maintenance (CMOM) approach. The CMOM approach is an information based approach to set priorities for activities and investments (Gatuan, 2003). EPA (Sept., 2002) regulated that sewerage system utilities experiencing SSOs or overflow violations at wastewater treatment plants should begin implementing the CMOM as soon as possible. Furthermore, the EPA (1970) recommended infiltration limits at a rate not to exceed 200 gal/in.diam/mi/day (185.2 cm.diam/km/day). Chemical grouting is among the most common methods to reduce the infiltration at sewer pipe joints.

Lateral joints are pipeline connections that branch off the main sewer and connect building sewers to the public sewer main. These connections enter mainlines at angles ranging from 30 to 90 degrees to the axial flow direction of the main lines.

The standard ASTM F 2304-03 “Standard Practice for Rehabilitation of Sewers Using Chemical Grouting” describes the procedures for testing and sealing individual sewer pipe joints with appropriate chemical grouts using the packer method [ASTM F 2304, 2003]. Among the grouting materials, acrylamide and acrylic based gel grouts have low initial viscosity, and quick and controllable setting time, and they are used for such leak control applications [Karol, 1990].

According to ASTM F 2304 (2003) no joint shall be considered sealed unless, a minimum of $\frac{1}{4}$ gal/in. of pipe diameter of grout is pumped under pressure. Chemical grout shall be pumped “to refusal” with a volume not to exceed $\frac{1}{2}$ -gal/in. diameter. The point of refusal is a point at which, during injection, grout flows through the joint failure into the surrounding soil and has gelled. At this point, the injection pressure rapidly spikes an additional 8 (55kPa) to 12 psi (83 kPa) above the prior pressure in a short period of 1 to 5 seconds [ASTM F 2304, 2003].

OBJECTIVES

The objectives of this study were (1) to investigate the grout movement through the unsaturated granular media surrounding the pipe joint using a 2D model; (2) to verify the performance of acrylamide grout in controlling leaks at the lateral joints; and (3) Develop a mathematical model to represent the grouted sand bulb around the joint

MATERIALS AND TESTING

Sand

Commercially available sand was used for this study. The sand had d_{10} , and d_{50} of 0.5 mm 0.95 mm, respectively. For this sand the coefficient of uniformity and gradation were 2.17 and 0.9, respectively.

Grout

A commercially available “AV-118 Duriflex” N-methylolacrylamide (NMA) grout (Avanti Grout International, Webster Texas) was used in this study.

Two-Dimensional (2D) Lateral Model

A two-dimensional (2D) model was designed to investigate the grout movement around a lateral pipe joint during grout injection. It was a chamber with internal dimensions of 12 in (310mm) high, 24 in (620mm) long, and 2 in (50mm) wide (Fig. 1). It was made with plexiglass, and was held together with stainless steel rods. Rubber gaskets and Teflon tape were used to ensure watertightness. A hole was opened at the center of the bottom plate allowing a vertical connection of 2 in (50mm) diameter pipe extending into the chamber that represented a 2 in. diameter lateral joint. The opening area between the pipe and bottom plate was 1.38 in² (8.9 cm²). Once the chamber was filled with sand two metallic plates were placed over it to simulate in-situ conditions.

The desired soil density was easily achieved by pouring the sand tamping it in 4 layers. After that, water was injected into the chamber using various injection pressures and the infiltration at the pipe joint were measured using test tubes. An infiltration test using the 2D model is shown in Fig. 1. Infiltration was measured before and after grouting at various water pressures that were gradually increased from 2 psi (14 kPa) to 4 psi (28 kPa).

The grout was injected from the bottom at a 3 psi (21 kPa) pressure through the leaking joint. The movement of the grout during injection was recorded up to 5 sec. using a Sony-Mavica video camera. The Grout movement was investigated using this video at 0.25 sec increments. Clamps were used to prevent the bending of watertight chamber body. The injection setup for the 2D model is shown in the Fig. 2.

TEST RESULTS AND DISCUSSION

(a) Infiltration Study

The chamber was filled with 450 ci (7500 cc) of sand. The sand's unit weight was 90.5pcf (14.2 kN/m³). The permeability of the sand was 1.5 x 10⁻³ in/sec (4 x 10⁻³ cm/sec). Infiltration at the leaking joint in the 2D model increased almost linearly with increasing water pressure. The infiltration was 540 gpd/in. diameter and 1440 gpd/in.diameter at 2 psi (14 kPa) and 4 psi (28 kPa) water pressures respectively. Infiltration values versus applied pressure are shown in the Fig. 3. infiltrations were above limit of 200 gpd/in.diam of pipe set by EPA (1977).

(b) Exfiltration Study

(i) UngROUTED Joint

Water was injected into the chamber using 3 psi (21 kPa), 5 psi (30 kPa), 7 psi (117 kPa), and 10 psi (690 kPa) pressures at the leaking joint and the water movement was recorded. The observations showed that the movement of water front through the unsaturated soil surrounding the pipe joint was ellipsoid like as shown in Fig. 4.

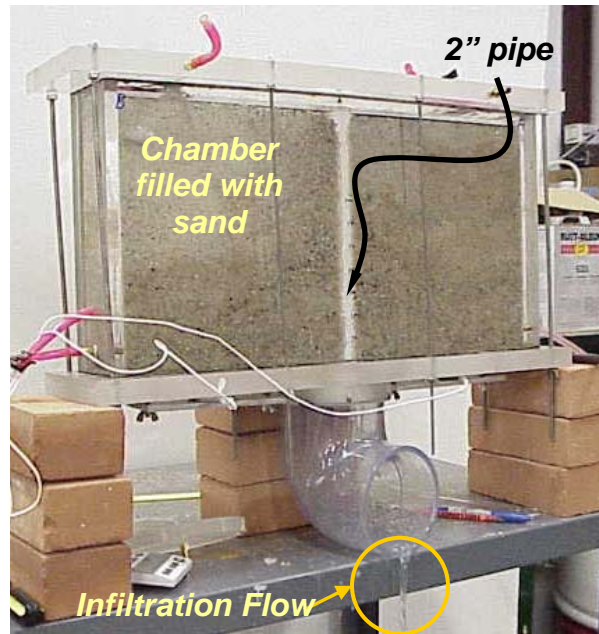


Figure 1. The 2D Model During Infiltration Testing

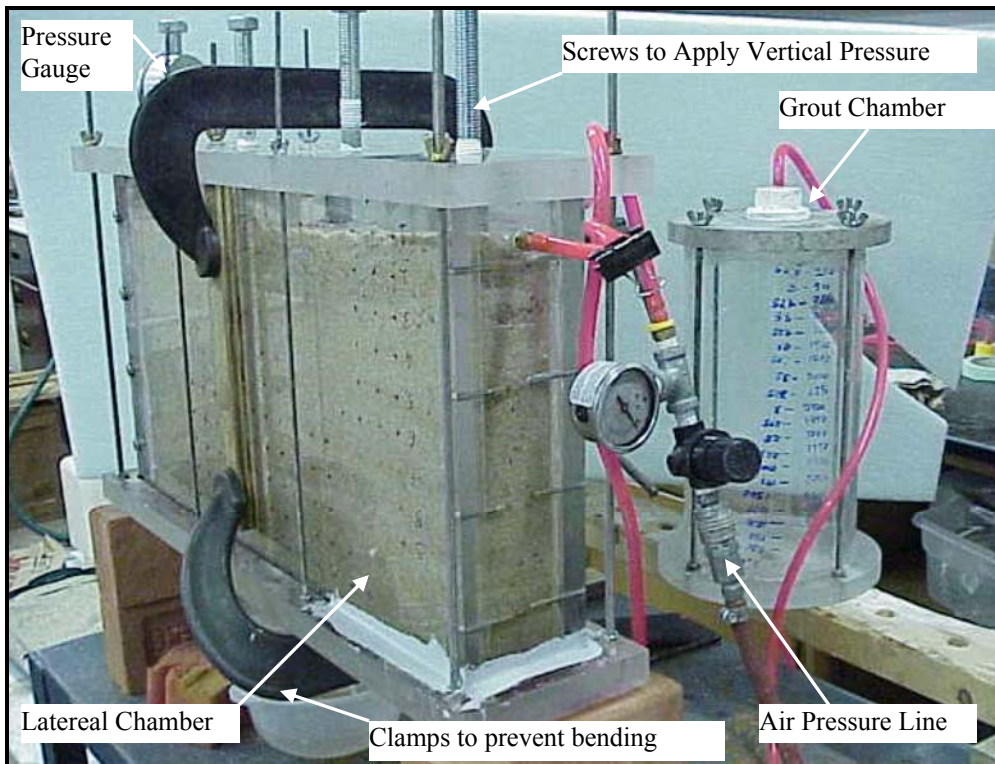


Figure 2. 2D Lateral Model Grout Injection Setup

The movement of water in the semi-minor (h) and semi-major (r) axes increased with injection time and injection pressure. The effect of injection pressure and injection time on the movement of water in the semi-minor (h) and semi-major (r) directions are shown in Fig. 5. and Fig. 6. respectively.

The average ratio of semi-minor to semi-major axis was (h/r) 0.6 and remained constant with varying injection pressure and time. The variation of h/r ratio with various injection pressures is shown in Fig. 7. The movement of acrylamide grout inside the chamber when injected at 3 psi is shown in Fig. 8. The h/r ratio for the grout ranged from 0.55 to 0.65

(ii) *Grouted Joint*

Using 3 psi (21 kPa) injection pressure, a total of 0.14gal (500 cm³) of acrylamide grout was injected into the chamber with a flow rate of 14 cm³/sec (0.86 in³/sec). The shape of the grouted sand around the lateral joint is shown in Fig. 9. At the end of grouting the grout movement on the semi-major (r) and semi-minor (h) axes were 6.25 in (15.9 cm) and 3.5 in (8.9 cm) respectively (h/r = 0.56). Even though there was a slight difference on the shape of the grouted sand on the right and left side of the chamber, measured “r” and “h” values were same. The Infiltration flow was measured after grouting using up to 6 psi (42 kPa) water pressure, but the joint was totally sealed, and the infiltration flow was zero.

The ASTM F 2304 recommends injecting a grout volume of 1/4 gal per in of pipe diameter, that would have resulted in pumping 0.5 gal of grout (1.9 L) for the joint with a circumference of 2π in. In this study, however, the model thickness was 4 in (both sides). Hence, following the ASTM recommendation 0.3gal (1.2 L) grout had to be injected to control the leak. Despite of that, the volume actually grouted was 0.14gal or 42 % of what was recommended by the ASTM

The fact that less grout volume was required to seal the leak could be partly due to the controlled and confined nature of the 2D model used in this study.

Mathematical Model

Starting form the point that the shape of grouted sand bulb in the 2D lateral joint can be idealized as shown in Fig. 10. Based on the acrylamide grout movement findings, the volume of injected grout based on void ratio of soil and the shape of grouted sand bulb can be represented as follows (Somasundaram, 2003).

$$\frac{V^G}{(R_0)^3} = \frac{1}{2} \frac{k^2}{R_0} \frac{\pi \chi \times d^{GS}}{\alpha \left[\frac{1+e}{e} \right]} \quad (1)$$

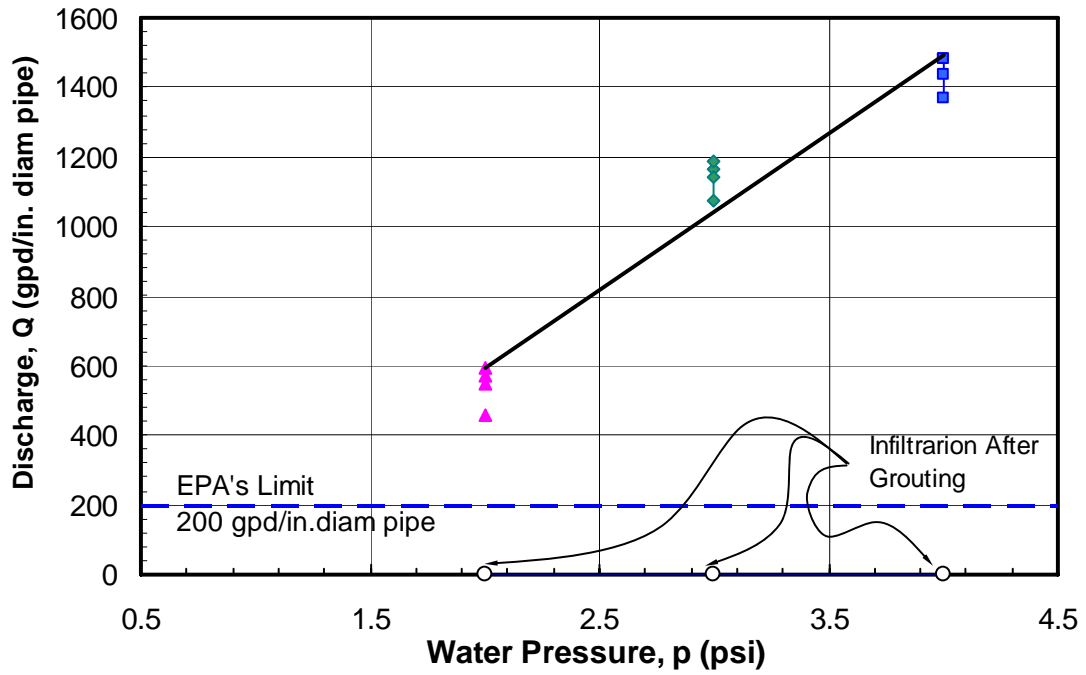


Figure 3. Infiltration Flow Before and After Grouting (145 psi = 1 MPa)

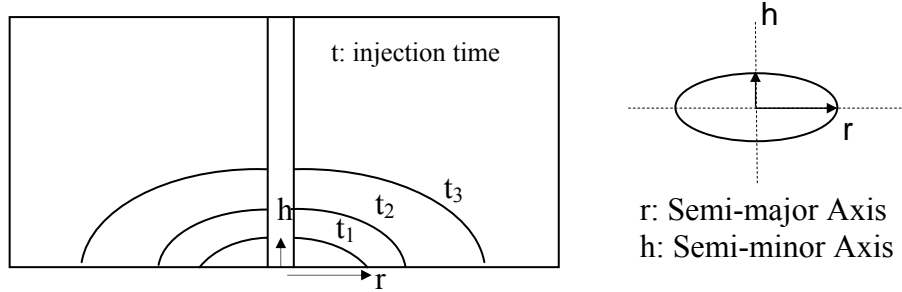


Figure 4. The Ellipsoid Shape of Water Movement in the 2D Model

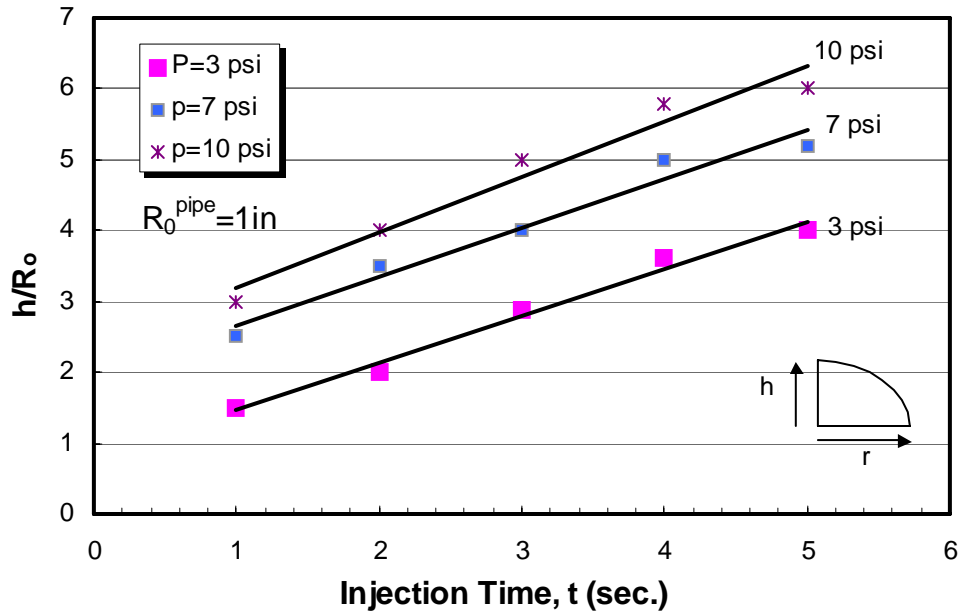


Figure 5. The Effect of Injection Pressure and Injection Time on the Movement of Water in the Semi-Minor (h) Direction (2D Model) (145 psi = 1 MPa).

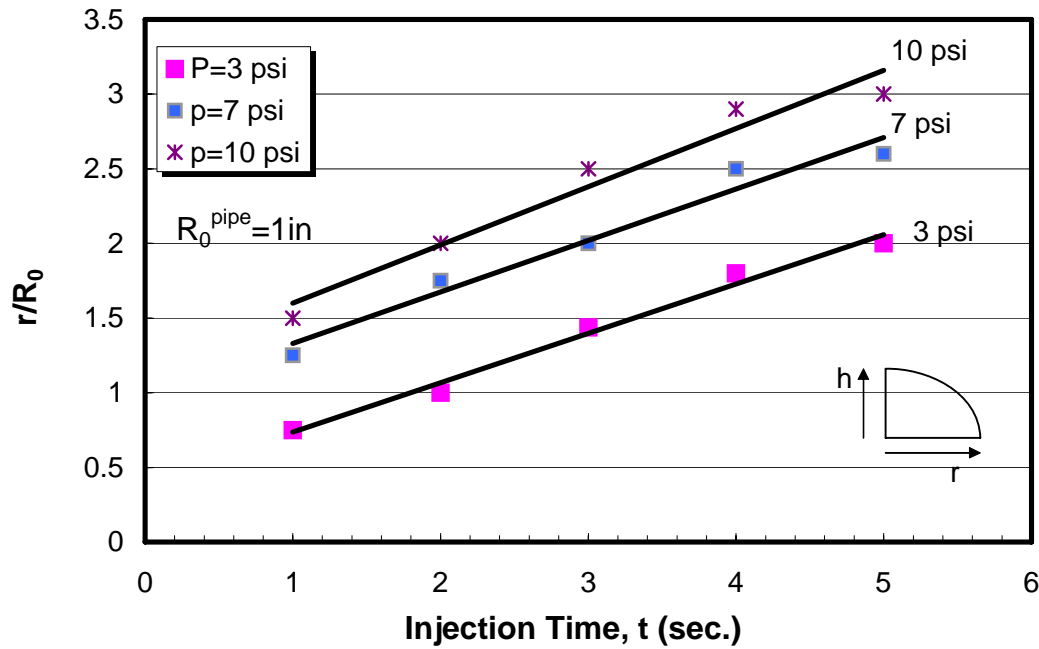


Figure 6. The Effect of Injection Pressure and Injection Time on the Movement of Water in the Semi-Major (r) Direction (2D Model) (145 psi = 1 MPa).

Where V^G is the volume of injected grout, R_0 is the radius of the lateral pipe, k the semi-major axis to the radius of the lateral pipe (r/R_0), χ = semi-major to semiminor axis ratio (r/h), $d^{GS}=2$ in. (width of chamber) for the 2D Lateral model, and the parameter α is the dilution factor which was defined as follows:

$$\alpha = \left[\frac{V^G + V_w}{V^G} \right] \quad (2)$$

Where V_w is the volume of additional water that mixes with the grout.

The 2D model prediction Eqn.1 on the grout volume for various void ratios and dilution factors and the actual injected volume are shown in Fig. 11 and Fig. 12. The volume of injected grout which forms the grouted sand bulb influenced by sand's void ratio, radius and height of the grouted sand bulb, and dilution factor (α).

In the 2D model using 3 psi (21 kPa) injection pressure, 500 cm³ (30 in³) grout injection into sand with void ratio of 0.65 resulted in a grouted sand bulb with $\chi = 0.56$, and $k=0.65$. Assuming $\alpha=1$, the volume of injected grout was calculated as 480 cm³ (29.3 in³) using the equation 1, and hence this relationship can be used in designing the extent of grouted sand bulb around the pipe joint.

CONCLUSIONS

A 2D lateral joint model was used to investigate the performance of acrylamide chemical grout in lateral pipe joint to control leak. The following conclusions are advanced based on the physical and mathematical model studies:

- (1) Using the 2D model the grout movement in the sand surrounding the lateral pipe joint was verified and modeled. The experiments showed that the movement of acrylamide grout in the sand surrounding the lateral pipe when injected 3 psi (21 kPa), was ellipsoid shaped with h/r ratio of 0.6. This ratio did not vary significantly when injection pressure was varied from 3 psi (21 kPa) to 10 psi (690 kPa).
- (2) Based in limited laboratory tests, the 2D model can be used to verify the effectiveness of grout in controlling leak at lateral joints. The acrylamide grout used in this study reduced the infiltration to zero.
- (3) Only 42% of the volume suggested by the ASTM standard was injected in this study to reduce the infiltration to zero. Less grout was needed to eliminate the infiltration because of the two-dimensional (2D) and confined nature of the problem.
- (4) The mathematical model was verified with limited data to predict the grout volume based on the grouted sand configuration around the joint.

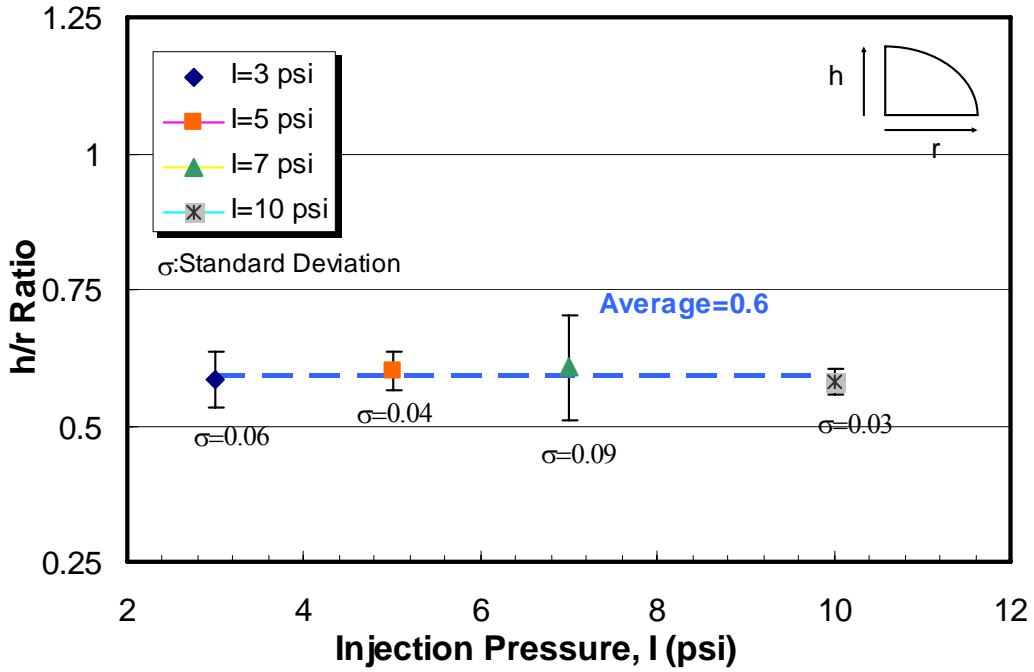


Figure 7. Variation of h/r Ratios at Various Injection Pressures

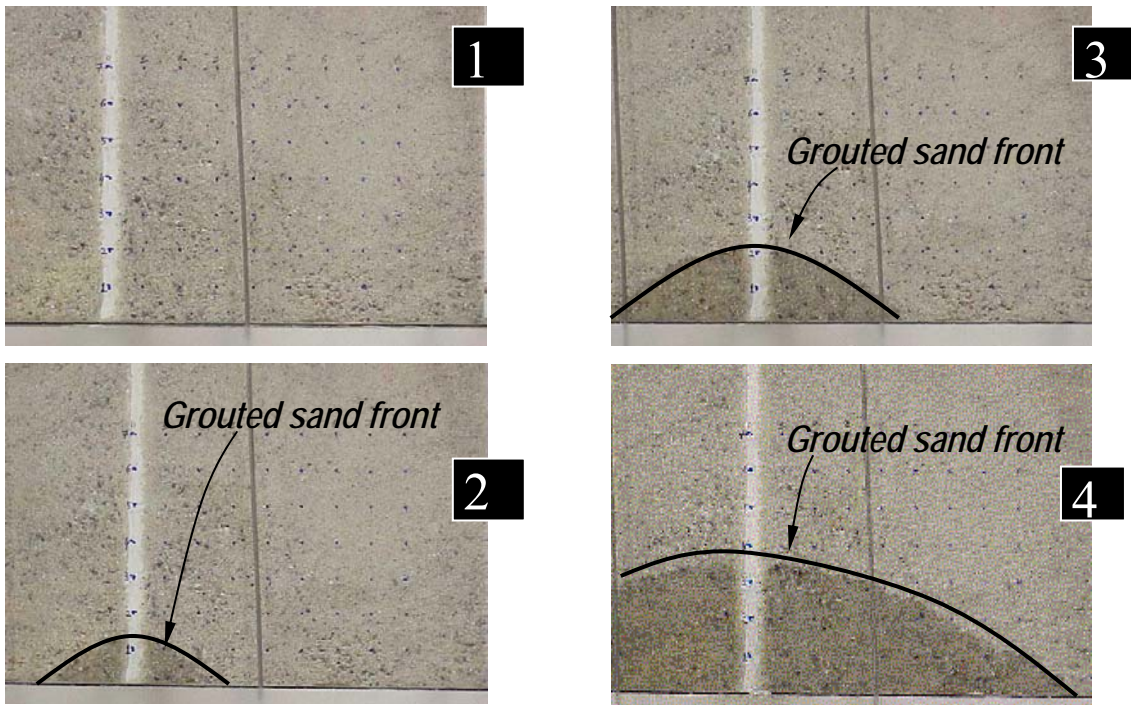


Figure 8. Acrylamide Grout Movement in the 2D Model (Injection Pressure= 3 psi (21 kPa))

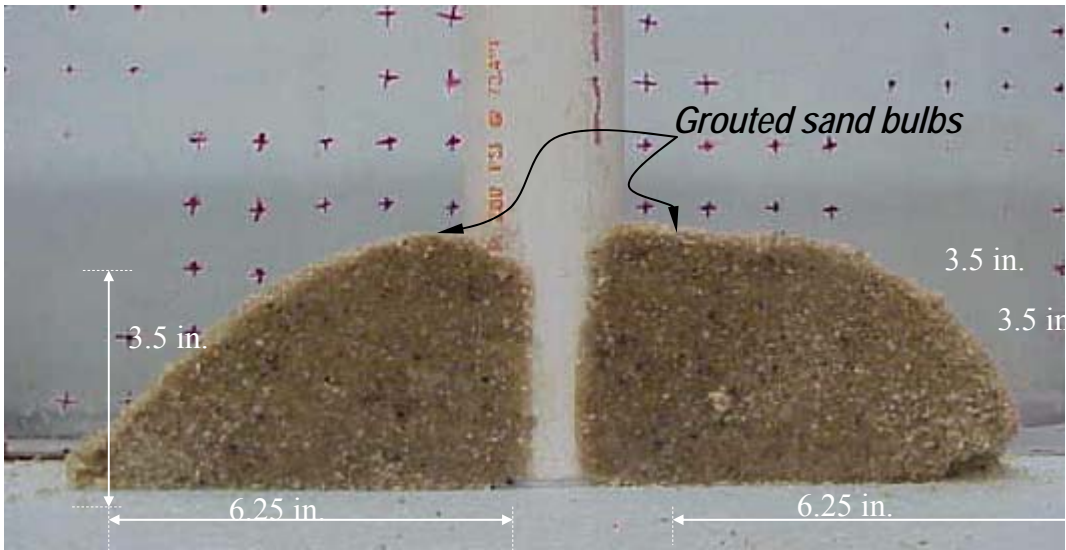


Figure 9. Grouted Sand Around the Lateral Joint

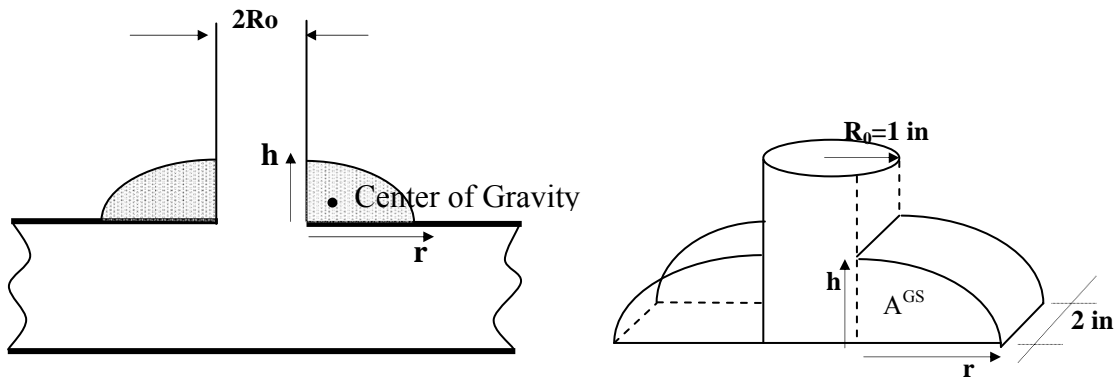


Figure 10. Grouted Sand Around the 2D Lateral Joint

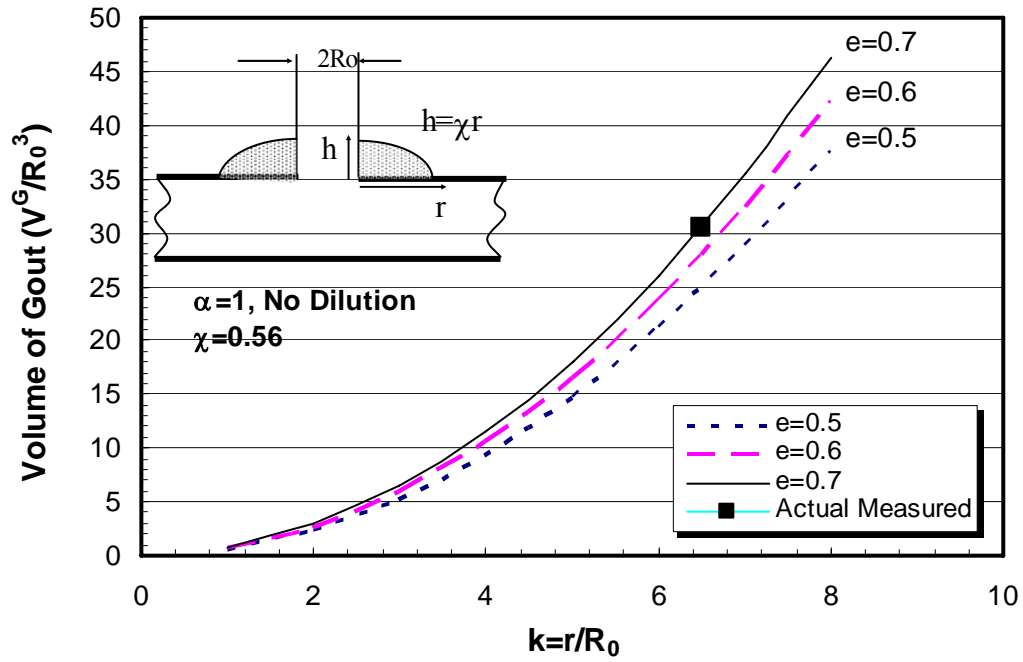


Figure 11. Effect of Void Ratio on the Predicted Grout Volume

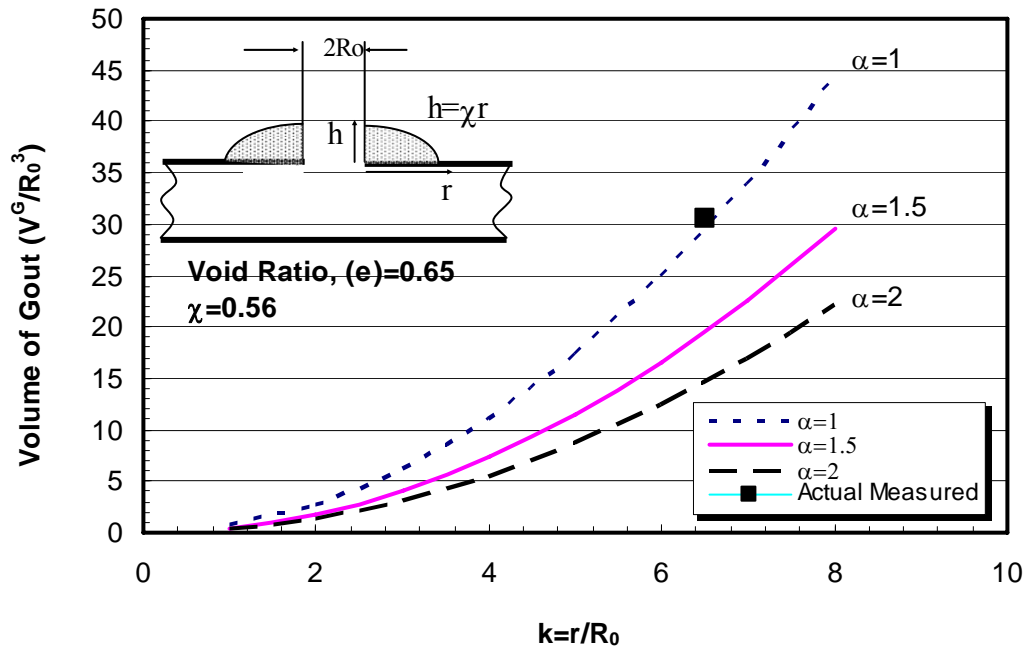


Figure 12. Effect of Dilution Factor on the Predicted Grout Volume

ACKNOWLEDGEMENTS

This work was supported by the Center for Innovative Grouting Materials and Technology (CIGMAT) with funds from NSF-International and private companies.

REFERENCES

ASTM (2003) “ASTM F2304-03 Standard practice for rehabilitation of sewers using chemical grouting”, ASTM standard: 1-8.

CIRIA (1997) “Control of Infiltration to Sewers,” Construction Industry Research and Information Association, Report No. 175,.

EPA (1970) “Control of Infiltration and Inflow into Sewer Systems”, Report #11022EFF12/70, Washington, D.C.

EPA (1977) “Sewer System Evaluation, rehabilitation, and New Construction: A manual of Practice,” Report # EPA600/277017d, Washington, D.C.

EPA (2002) EMS Integration Project Final Report with WAF, September, Washington, D.C. http://www.epa.gov/epaems01/Final_report.pdf.

Gatuum, P. (2003) “Population Based Model to determine Life Cycle Cost of a Wastewater System”, M.S.C.E. Thesis, Department of Civil and Environ. Engng, University of Houston, Houston, Texas.

Karol, R.H. (1990) Chemical Grouting, 2nd ed., Marcel Dekkere, Inc., New York, NY.

Somasundaram, S. (2003) “Behavior of Flexible and Rigid Polyurethane Grouts Used for Controlling Water Leaks,” M.S.C.E. Thesis, Department of Civil and Environ. Engng, University of Houston, Houston, Texas.