Flood Grouting Sanitary Sewers for Infiltration Control

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ABSTRACT: The 1950s-era concrete pipe sanitary sewer system in Seattle’s Broadview neighborhood experiences significant wet weather inflow and infiltration. Extreme wet weather events have resulted in sewer overflows into private residences and the environment. Previous work indicates that the majority of flow during wet weather is infiltration. For an infiltration reduction project to achieve maximum success, all components of the sewer system—mainlines, maintenance holes, and private side sewers—have to be addressed. An alternative analysis indicated that infiltration reduction using flood grouting, as provided by Sanipor®, was the most cost-effective, least disruptive methodology.

Flood grouting involves isolating and treating an entire section of the sewer system between two maintenance holes, including the side sewers, with two chemicals in separate steps. The segment is filled completely to the rim and utilizes hydrostatic pressure by the chemical fluid to apply the grout to portions of the system that are prone to leakage. Because of this technique, there is little risk that potential infiltration sources will be missed.

To determine the success of the project, flow meters have been installed in the system to document before and after conditions for modeling analysis. Infiltration removal rates, costs, challenges associated with working on private property, and lessons learned from this flood grouting project are documented in this paper.

Flood grouting has been used in limited applications in the U.S., but never in the Pacific Northwest. This is the largest flood grouting project in the U.S. to date.

1. INTRODUCTION

This paper documents a pilot project completed by Seattle Public Utilities (SPU) to reduce infiltration into its separated sanitary sewer system in the Broadview neighborhood of Seattle. The rehabilitation method chosen for this pilot project is called flood grouting. This method reduces infiltration by sealing large portions of a system all at the same time, including sewer mains, private sewer laterals, and maintenance holes (MHs) with a two-part chemical process. The initial steps to selecting this technology, a detailed explanation of what flood grouting is, a construction description, costs, and initial effectiveness are described.

2. BACKGROUND

Located in the northwest section of Seattle (Figure 1), the Broadview neighborhood has experienced repeated wet weather sanitary sewer overflows from both MHs and into basements during extreme storm events in this separated
sewer system. This area of the city was built mostly in the 1950s, with the sewers made of concrete pipe. Over time, the pipes have deteriorated, allowing excessive amounts of infiltration through separated joints, fractures, and other defects. The environment and residences along 12th Avenue NW have been hit particularly hard with numerous backup events. The pilot project area is the most upstream section of this sub-sewershed. As shown in Figure 2, the project site contains 88 residences, 5,900 feet of 8-inch-diameter mainline pipe, 9,750 feet of 4- and 6-inch-diameter private side sewers, and 27 MHs.

Previous engineering studies\textsuperscript{1,2} have included a closed-caption television (CCTV) inspection, smoke testing, and flow monitoring. The CCTV inspection was completed during the dry summer months so no or little active infiltration was recorded. However, staining, mineral deposits, and encrustation support the conclusion that the defects and open joints are infiltration sources. The smoke testing revealed that about 10 percent of the houses in the overall Broadview area have their downspouts and other minor stormwater devices connected to the separated sanitary sewer system. A flow monitor has been in place at the bottom of the 12th Avenue NW basin for over a year, and another flow meter has been installed since February 2011 at the first MH downstream of the pilot project area.

The CCTV, smoke testing, and flow meter data were used to build a hydraulic model of the 12th Avenue NW basin. The modeling determined that excessive infiltration is indeed the leading cause of the wet weather backups. The modeling also revealed that if infiltration is significantly reduced, upwards of 80 percent, wet weather backups will be reduced, if not eliminated. Only marginal reduction in flows resulted when inflow was removed from the system; therefore, infiltration was targeted for removal. To achieve a significant infiltration reduction, the private side sewers have to be addressed in addition to the SPU-owned and -maintained mainline sewers and MHs.

3. PROJECT OBJECTIVES AND SELECTION

Before selecting the rehabilitation technology to reduce infiltration in the selected basin, the following three criteria were set:

1. Technology must reduce infiltration from the private side sewers
2. Technology must be minimally disruptive
3. Technology must be economical

A business case evaluation (BCE) was completed evaluating cast-in-place pipe lining (CIPP), pipe bursting, joint grouting, and flood grouting. Open-trench replacement was not considered because it does not meet criteria 2 and 3,
listed above. After the benefits and costs for each of the four rehabilitation technologies were compiled, the technology with the greatest benefit-cost ratio was determined to be flood grouting, which was thus selected for project implementation.

Because work had to be completed on private property with the installation of cleanouts to prevent the chemicals from getting into the houses, public participation was a critical project element. SPU conducted an extensive public relations campaign to gain public support. SPU held a neighborhood public meeting where the project was introduced to the community. Informational mailings with rights-of-entry forms were then mailed to the houses directly affected. A second public meeting was held to present the project in more detail to the pilot area. SPU sent third and fourth mailings, called houses, and sent certified mailings to addresses that did not respond within the identified response period. Through this work SPU was able to achieve a 95 percent participation rate. In addition to this pre-construction work, SPU conducted an open house in the community with the flood grouting contractor, Bravo Environmental, to show the equipment that would be used for the project to the public.

4. FLOOD GROUTING

Flood grouting is the process of internally flooding an entire segment of sewer (MH to MH) and the side sewers all at once with a two-part chemical process that leaches out to the surrounding soil through pipe defects to seal the pipe from infiltration. The two chemicals react with each other to form a gel and bind the surrounding soil to create a watertight seal. As can be seen in Figure 3, the chemicals leach out 8–12 inches from the pipe, resulting in a sandstone-like structure where the chemicals interact with the surrounding soil. The chemicals and technical expertise for this project were provided by Sanipor®. The chemicals used in the system are silicate-based and are non-toxic to the surrounding soil and groundwater, as has been confirmed by several German and other European authorities and institutions that have tested this technology

The first step in the flood grouting process is to inspect internally all side sewers, mainlines, and MHs to locate any defects that need to be repaired. Flood grouting is a nonstructural repair method and any serious structural defects that are located have to be repaired prior to grouting. The inspection also assists in locating existing cleanouts on side sewers and in the placement of new cleanouts if they are needed. Ideally, cleanouts are installed as close to the buildings as possible to maximize the extent of the side sewer that can be sealed. If cleanouts are required, the Vac-A-Tee (or similar) process is recommended, as shown in Figure 4. This minimally invasive process utilizes vacuum excavation to expose the side sewer to determine where a new riser pipe can be attached.

![Figure 3. Sanipor® demonstration: Sandstone-like structure where Sanipor® has interacted with surrounding soil](image-url)
Following installation of the plugs and flushing of the segment, the sewer segment is filled to the top of the MHs with the first of the two chemicals, S1, which has a liquid gel-like consistency. S1 is allowed sufficient time to exfiltrate the system into the surrounding soil and is then immediately pumped out of the sewer system back into a tanker truck for reuse in the next pipe segment. The entire segment is then jetted to remove any S1 chemical from the interiors of the pipes and MHs. The process is repeated with the second chemical, S2, which has a watery consistency. Because S2 behaves similarly to water, the rate at which it exfiltrates the system can be used as the “after” exfiltration rate to document the immediate effectiveness of the grouting process. Depending on leakage rates, the S1/S2 process can be repeated several times on each segment to ensure that the system is properly treated. A typical MH-to-MH reach, including all connected side sewers, can be completed in about 8–10 hours. Figure 5 depicts the steps of the flood grouting process.

The significant advantage of flood grouting is that it simultaneously treats all three components of the sewer system (MHs, mainlines, and side sewers). It seals all possible leaks in the system from infiltration, including those that are not visible during inspections. Once the chemicals react with each other, they also serve as a root inhibitor helping keep roots out of the sewers.

5. **CONSTRUCTION**

The implementation phase of the project began in July 2011 with the initial cleaning and CCTV inspection of the mainlines. The mainline sewers were generally found to be in good shape. No large collapses, root balls, or other significant defects were located. Significant signs of infiltration (staining, encrustation, and drippers) were identified. The CCTV inspection found three pipes that transitioned mid-reach from 6 to 8 inches in diameter. The transitions consisted of the smaller-diameter pipe inserted into the larger-diameter pipe. On those same lines, the upstream MH was actually a lamp hole (cleanout on the mainline). The lamp holes did not provide the access needed for the inspection, cleaning, or grouting. SPU installed pre-cast MHs at these locations under its operations and maintenance budget and the associated costs were not included in this project.

Once SPU received a significant number of right-of-entry forms from homeowners, inspection and installation of the cleanouts began. The majority of the homes were inspected using side-launch cameras from the main sewer line. The inspection not only determined the condition of the lines, but also was used to assist in locating potential
cleanout installations. The majority of the houses had multiple laterals branching off to various locations of the house. The cleanout would be positioned downstream a few feet from the most downstream branch. This also included side sewers that served multiple houses. Several of the houses could not be inspected from the mainline for several reasons. At these houses, push cameras were used through existing inside cleanouts or by removing toilets and inserting the camera through that opening. The inspection of the side sewers revealed that the geographic information system (GIS) mapping of the side sewers in this area was incorrect at several locations. The side sewers were found to be in similar condition as the mainlines.

Following inspection, the cleanouts were installed at the locations identified by the internal inspection. In some instances landscaping and homeowner approval modified the previously identified locations. Due to the multiple branches, landscaping, and homeowner approvals, approximately only 30 percent (about 3,000 feet) of the total side sewer length could be sealed. The cleanouts were installed by the Vac-A-Tee method as previously described. Generally this operation went smoothly, except in a few locations where the locates from the internal inspection were off. In these circumstances the excavated hole ended up being larger then it would have been if the locate was correct.

The first flood grouting operations began on August 10, 2011, and were completed on October 5, 2011. Prior to any sewer shutdowns, homeowners received notice 4 days and again 1 day before operations that they could not use water during the grouting process, generally from 9 a.m. to 6 p.m. The flood grouting process consisted of a pre-cleaning of the MHs, mainlines, and side sewers. Next plugs were installed in upstream and downstream MHs in the mainline pipe and side sewers through the newly installed cleanouts. Special long and narrow plugs were obtained for the side sewers to facilitate their insertion through the cleanouts.

Once all the plugs were installed, S1 was discharged into the upstream MH and allowed to fill the entire system until the liquid level reached the upstream MH rim. The liquid level was measured every 5 minutes to monitor its exfiltration rate. If the liquid dropped excessively, the level was topped off to maintain the maximum possible hydrostatic pressure on the system. After a period of 30 to 45 minutes, S1 was extracted out of the MH back into the vactor truck. The system was then rinsed to remove as much S1 from the inside of the pipes as possible to keep S1 and S2 from reacting inside the pipe, potentially causing a blockage. All of the plugs were reinserted and the process was repeated with S2.

In several instances, S2 did not achieve the desired exfiltration rate. In these cases the whole process was repeated until the segment achieved the desired sealing goals. The sealing goal, provided by Sanipor® based on European acceptance of new concrete pipelines, was set at an allowed exfiltration rate of 0.74 gallons per 100 square feet (0.3L/m²) of wet inner surface in 30 minutes. The exfiltration depths were recorded and are stored in graphs as shown below in Figure 6. In some locations, as is shown in Figure 6, the upstream MH was treated separately from the mainline to minimize chemical loss and assist in achieving the greatest sealing potential.

Only four to five segments required actual bypass pumping during the grouting operations. Typically the upstream pipe could store any received flows or a flow-through plug could be used to transport sewage through an MH without contaminating the grout.

At the end of the flood grouting state, a significant amount of the flood grouting chemical was left over. Of the 18,000 gallons of S1 ordered 9,600 gallons remained, and of the 9,000 gallons of S2 ordered 5,200 gallons remained. This was due to a couple of issues. The volume ordered was estimated on sealing the full length of the side sewers, but only 30 percent of the side sewer length was sealed. Second, the infrastructure sealed using less chemical than anticipated. Lastly, Sanipor® included a safety factor in its order because the chemicals have an 8–10-week lead time to be shipped from the manufacturer, EKA Chemicals, Inc., and did not want to shut the project down for that time period should the chemicals be used up prior to completion. SPU plans to utilize the remaining chemicals by sealing just MHs in other sections of the 12th Avenue NW basin. Sealing MHs is a simpler process than when the mainlines and side sewers are included. No public notification or bypass pumping is required and it can be completed in all weather conditions.
Construction Equipment

The following large-scale and special equipment was required for the actual flood grouting process:

**S1 Truck**
- 2008 Vactor 2115 centrifugal compressor combination sewer cleaner (fan unit)
- 15-cubic-yard debris barrel
- 2,500 gallons of liquid storage (S1)
- 5-axle 68,500-pound gross vehicle weight (GVW)
- 0 to 8,000 cubic feet per minute (cfm): operating range 2,500 to 4,500 cfm

**S2 Truck**
- 2007 Volvo VHD swap loader
- 4,200-gallon Predator vacuum body (roll off)
- 550 cfm Fruitland rotary vane vacuum pump
- 7-axle 78,500-pound GVW (single), 105,500-pound GVW (tandem)
Sewer Plugs
10 - 4" Logiball pneumatic side sewer plugs
10 - 6" Logiball pneumatic side sewer plugs
4 - 6" to 12" pneumatic blocking plugs
4 - 6" to 12" pneumatic flow through (3") plugs
4 - 8" to 12" pneumatic flow through (4") plugs

Construction Challenges

Numerous challenges and obstacles were encountered during the grouting process. First and foremost was the topography of the project site. The site is hilly and has considerable elevation differences between upstream and downstream MHs and the high and low sides of the street. The worst-case MH-to-MH reach had a 30-foot difference in rim elevations. To maximize the application of the grout, riser pipes were installed on low-side cleanouts to help manipulate the hydraulic grade, as shown in Figure 7.

Figure 7. Riser pipes

Another challenge was that at three locations the chemicals fracked out from cracks in the pavement on the downhill side of pipe segments. A small amount of liquid was observed seeping out and projecting up in the air 2 to 3 inches. In these instances, the chemical elevation was immediately brought down and the application continued in lifts to slowly seal the higher pipes. When S1 is allowed to dry on the surface, it solidifies with a glass-like consistency. Immediate and thorough spill response is a necessity.

Chemical S1 has a specific gravity of 1.4. Because of this, the contractor had to be very careful about how much chemical he could put in the tanker trucks before exceeding weight limits (the trucks would be overweight before the tanks were full). In addition to the loading concerns, the contractor had to send the truck used for S1 to the shop for repairs on the brake system twice during construction due to the heavy loads and parking on the steep streets. Also because of S1’s weight, a very large pump is needed to be able to quickly pump out the liquid from the sewer system. The grouting application needs a very quick transfer from S1 to S2 to properly seal the system and avoid having S1 either leach back into the pipes or migrate too far away in the soil before it can react with S2. The contractor had to switch trucks that contained each chemical because the pump on the original S1 truck was not powerful enough to pump the heavy chemical.
One of the known and accepted risks of this project was the potential to flood a basement with either clean water during a clean water test or with one of the two chemicals. Unfortunately, this happened three times on this project. The first instance involved the air hose getting wrapped up in the side sewer plug. This created a passage for S1 to enter a basement a couple of inches. Following this, the contractor began inserting a push camera down deep cleanouts to visually confirm that the plug and air hose were properly installed. The second instance was during a clean water test, when two basements from houses that shared a side sewer were filled with a couple of inches of water. It is believed that the plug did not seal properly against the rough, aggregate-exposed concrete side sewer. This house was on the downhill side of the segment, and thus experienced significant pressure. After this, the contractor installed a second cleanout on a house that would receive high pressures to install a second backup plug. The final instance involved several inches of S1 getting into another basement. This was caused by incomplete mapping and missing a second side sewer to a house during internal inspection. This occurred at the very end of the project, but the lesson learned is that complete mapping, matched up to the internal inspection data, is critical.

6. **COST**

**Project Costs**

SPU was very conscientious about tracking all associated costs with this project. At the onset of this project, SPU tracked all costs associated with work on it. This included preparation of the BCE, flow monitoring, public relations, and preliminary engineering. The money spent prior to construction was as follows:

- SPU: $58,000
- Outside consultants: $80,000
- Total: $138,000

The construction-phase costs were also tracked. These costs are broken down to SPU-related, outside consultants, and actual construction:

- SPU: $117,000
- Outside consultants: $29,000
- Construction: $883,000
- Total: $1,029,000

It is estimated that up to an additional $200,000 will be spent between SPU and outside consultants on project closeout and evaluation. Therefore, the total estimated money spent on this project from initiation through evaluation and closeout is as follows:

- Preliminary selection and engineering: $138,000
- Construction: $1,029,000
- Project closeout and evaluation: $200,000
- Total: $1,367,000
Construction Costs

The actual construction cost breakdown is presented in Table 1.

Table 1. Construction Costs

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Unit</th>
<th>Quantity</th>
<th>Unit cost</th>
<th>Total cost</th>
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<tbody>
<tr>
<td><strong>Pre-inspection/cleaning</strong></td>
<td></td>
<td></td>
<td></td>
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<td>Pre-inspection CCTV</td>
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<td>lf</td>
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<td>$0.90</td>
<td>$5,310</td>
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<td>Pre-clean</td>
<td>Mainline</td>
<td>lf</td>
<td>5,900</td>
<td>$0.90</td>
<td>$5,310</td>
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<td>Pre-inspection CCTV</td>
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<td>each</td>
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<td>$250</td>
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<tr>
<td>Pre-clean laterals</td>
<td>Laterals</td>
<td>each</td>
<td>85</td>
<td>$200</td>
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<td><strong>C/O installation</strong></td>
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<td></td>
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<tr>
<td>Cleanout installation</td>
<td>Labor/equipment</td>
<td>each</td>
<td>85</td>
<td>$703</td>
<td>$59,755</td>
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<td>Vac-A-Tee cleanout materials</td>
<td>Material &amp; special tools</td>
<td>each</td>
<td>85</td>
<td>$601</td>
<td>$51,085</td>
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<td><strong>Sanipor® work</strong></td>
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<td></td>
<td></td>
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<tr>
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<td>Two separate cleanings</td>
<td>lf</td>
<td>5,900</td>
<td>$1.50</td>
<td>$8,850</td>
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<tr>
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<td>Sanipor® process</td>
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<td>30</td>
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<td>Sanipor® mob/engineering</td>
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<td>each</td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>$883,000</td>
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</table>

One of the challenges of developing a unit cost of flood grouting is that it is applied to all of the sewer system components at once. Traditionally, side sewers, mainlines, and MHs all have separate unit costs for rehabilitation, because different methods are applied to each. For simple comparison, the flood grouting will be assessed on a linear-foot (lf) basis. The unit price from this project will be the sum of the side sewers (2,940 lf), mainlines (5,900 lf), and the vertical footage of the MHs (260 lf) that was actually sealed divided by the construction costs. The total length of the sewer assets sealed was 9,100 feet. This results in a unit cost of $97/lf. The total project cost is $150/lf.

As previously stated, a significant volume of chemical was left over after the completion of the grouting. This remaining volume has a value of about $180,000. If the leftover chemical value is subtracted from the construction cost, the construction cost is reduced to $703,000, resulting in a unit cost of $77/lf.

Because this was the first time that the contractor has worked with flood grouting chemicals, additional resources were allocated for having Sanipor® officials to be present to supervise, train, and conduct the grouting. This was an additional $96,500. The contractor is now well-versed in the flood grouting process, and would no longer need this additional cost for future projects. Reducing the chemical used cost of $703,000 by $96,500 equals $606,500, which reduces the construction unit cost to $67/lf.
The BCE developed cost estimates for the alternative infiltration control technologies of joint grouting, CIPP lining, and pipe bursting. The cost estimates for each of those methods also included separate MH rehabilitation because they do not seal MHs. The estimated construction unit cost estimates and the actual flood grouting unit cost are as follows:

- Joint grouting: $50/lf³
- Flood grouting: $67/lf
- CIPP lining: $120/lf³
- Pipe bursting: $120/lf³

The sewers within the project area have a fair number of cracks and other defects that would not have been sealed by joint grouting. While joint grouting is less expensive than flood grouting, it is believed that this method would not have sealed the sewers as well as flood grouting, due to the limitations described earlier, and therefore has a lower effectiveness.

7. EVALUATION

One of the benefits of flood grouting is that it provides immediate results on the post-exfiltration rate of the system. The exfiltration rate of the S2 chemical, which has a water-like consistency, can be used to determine the immediate post-flood grouting leakage rate. The leakage rates are determined by measuring the drawdown of the liquid from a reference point (usually MH rim) in 5-minute intervals and estimating the volume from the MH diameter. The post-exfiltration rate percent improvement for each of the 27 sewer segments ranged from 94 percent to 100 percent improvements, with an average improvement of 99 percent.

A network of four flow meters is installed to evaluate the actual reduction in wet weather flows in the sewer system. This includes metering a control basin to account for seasonal variability. These meters have been in place for the previous wet weather season to obtain the before infiltration rates and will be maintained for the 2011–12 wet weather season to obtain the post-wet-weather infiltration rates. The evaluation will be conducted using WERF protocol 99-WWF-85. This includes detailed hydraulic modeling and statistical analysis to determine the effectiveness of the project, expected to begin in April 2012. This project has received grant funding from WERF and the final project report detailing the effectiveness is due to be completed in December 2012.

8. REFERENCES


4. Sanipor®.