When Engineers, Contractors, and Manufacturers Collaborate – Improvements in Chemical Grouting Practices from the Sullivan's Island Construction Management at Risk Project

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ABSTRACT

Chemical grouting has been widely implemented as a sewer repair technology for more than five decades; unfortunately, often incorrectly. This is largely due to a poor understanding by engineers and owners regarding important design and field variables, key field performance needs, and the need of contractors to compete in a low price market while complying with ill-informed specifications and ill-conceived pay bases.

This paper presents new key findings regarding the design and implementation of chemical grouting for I&I leakage control as revealed during the Construction Management at Risk (CMAR) sewer rehabilitation project in Sullivan's Island, SC. This alternative project delivery work featured a remarkable collaboration between engineering, contracting, and manufacturing that significantly furthered the practical science of chemical grouting as a technology for structurally stabilizing and significantly reducing leakage over an extended period of time from gravity sewer pipes.

KEY WORDS: I&I reduction, Sewer Rehab, Grouting

BACKGROUND

Grouting is simple, quick, and relatively inexpensive compared to other rehabilitation technologies. Its main limitation is that it cannot repair broken or deformed pipes, as other rehabilitation methods such as pipe lining can. It is highly effective, however, on structurally sound pipes and laterals that are admitting groundwater through the joints and, with the advent of recent technologies, the most common types of structural defects, including longitudinal and multiple fractures. Targeted pipes are most often clay pipes, which, properly installed, seem to last forever, but, unfortunately, whose jointing materials in the past were not so long lasting. When a utility has identified leaking but otherwise generally structurally sound sewer pipes and manholes, grouting is usually the cheapest initial and life cycle cost solution. Two recently completed comparisons of I&I control methods for two sewersheds for two different utilities showed the following initial capital cost, life cycle cost, and cost per percent of I&I removed for both initial and capital costs.

Table 1 – Technology Comparison – Utility A

Recent Bid Prices	Cost per foot	Cost per lateral	Sewershed Statistics		Total Construction Cost of Approach	Likely I&I Reduction	Cost per I&I Percent Reduction	Minimum Life	50 Year Cost per I&I Percent Reduction
			Feet of Main	*Laterals*					
Test and Seal	$ 18.53		38,521	467	$ 713,794	40%	$ 17,845	25	**$ 35,690**
Mainline Lining Alone	$ 55.67		38,521	467	$ 2,144,464	15%	$ 142,964	50	**$ 142,964**
Lateral Lining/Replacement w/Cleanout Install		$ 8,512	38,521	467	$ 3,975,104	10%	$ 397,510	50	**$ 397,510**
Mainline Lining + Lateral Lining/Replacement w/Cleanout Intall	$ 158.86		38,521	467	$ 6,119,568	70%	$ 87,422	50	**$ 87,422**

Table 2 – Technology Comparison – Utility B

Alternative	Description	Total Capital Cost	Minimum Life	50 Year Life Cycle Cost	RDII Reduction Effectiveness Range			Capital Cost per Reduction Point	Life Cycle Cost per Reduction Point
1	Test and Seal - Public (50% of system) Only	$ 840,000	25	$ 1,500,000	10%	20%	25%	$ 42,000	$ 75,000
2	Mainline Lining and Tap Grouting - Public (50% of system) Only	$ 1,410,000	50/25	$ 1,690,000	10%	20%	25%	$ 70,500	$ 84,500
3	Mainline Lining and Lateral Lining - Public (50% of system) only	$ 3,390,000	50	$ 3,390,000	20%	30%	40%	$ 113,000	$ 113,000

Properly conducted, grouting offers very good I&I reduction benefits across the short, medium, and long term, It also provides reduced O&M costs (due to soil leakage into the pipe), prevents/slows the progress of pipe structural failure, and extends pipe life. Key is the understanding how to design and implement the technology properly. The Malcolm Pirnie 2009 No Dig paper titled "Pipe Line Grouting – Design for Longevity", the 2010 ASTM F2304 Standard Practice for Sealing Sewers Using Chemical Grouting, and the 2012 NASSCO guide specification for Pressure Testing and Grouting of Sewer Joints, Laterals, and Lateral Connection outline the fundamental requirements for properly conducting sewer grouting.

THE POWER OF COLLABORATION

When the Town of Sullivan's Island elected to implement their sewer grouting program using a Construction Manager at Risk approach, this team was presented with an opportunity to collaboratively synthesize the knowledge and experiences of engineer, several grouting contractors, material manufacturer, and equipment manufacturers into comprehensive grouting plan. Over the course of a 3 month pre-construction scoping, specification, and costing period followed by a 6 month construction period, each team member contributed their experience, opened their mind to method changes, and trialed many new practices. The result of this collaboration was an effusion of new realizations, concepts of practice, invention of tools, and challenges of both old and new concepts of grouting.

FINDINGS, OBSERVATIONS, AND RECOMMENDATIONS

Articulating grouting performance objectives

Collaboration revealed that only so much can be communicated in specifications. What engineers think they are writing and what field technicians believe they are reading are often very different. While the project had a solid set of specifications, successive discussion about what we wanted to achieve, and the manner in which they could actually be achieved, were needed to reach expected performance levels.

The first rounds of discussion were between the engineer and the subcontractors' project managers and estimators. These three parties worked out the bulk of the issues that impacted costs and schedule, many of which are discussed below. These discussions shaped the general approach, including the atypically rigorous grout mixture, testing, and equipment requirements, pay basis, and production schedule.

The second round of discussions was between the engineer and the field foreman directing the actual grouting. These conversations began the first day of construction, and continued continuously until job completion. These discussions centered on equipment, material, and process needs to achieve the desired results.

Benefit of setting the cost of grout

Grout crews are trained to use minimal grout to seal leaks, because grout is the single biggest non-labor cost on a grouting project. But with a goal of 3 gallons of grout per leaking mainline joint (about 3 times the average of a typical low-bid grouting project), this mindset worked counter to our objectives. Setting the cost of grout at a price approximately 10% higher than the cost to purchase the materials and make up the grout provided a slight business incentive that helped overcome this bad habit.

Benefit and cost of higher concentrations of acrylamide to in-situ grout strength, especially in a very wet environment

Acrylamide grout is typically made with a 10% acrylamide concentration. Higher concentrations of acrylamide provide stronger grouts, resulting in a stronger, less friable soil-gel mixture. Bench scale testing established an optimize grout mixture of 12% acrylamide. The additional 20% solids provided a denser solidified grout that, when mixed in situ, mixed well with surrounding soils, provided unconfined compressive strengths 50% higher than the 10% mix, and retained sufficient flexibility and tackiness to seal the defects. The stronger grout appears to provide greater longevity and reliability of seal.

The 12% mixture was achieved by using a standard full bag of grout, but simply filling the A and B tanks to only 25 gallons per tank (dropping the batch volume from 60 gallons to 50 gallons).

A 12% mixture of grout cost ~15% more for material than a 10% mixture, but no additional labor cost to prepare. Prepared costs for 10% mix is ~$10 per gallon versus a cost for 12% mix of ~$12 per gallon.

Benefit and cost of latex to grout tackiness, strength, and long-term sealability

Latex was added to the 12% grout mixture to add strength, tackiness, and longevity to the seals. The project began using 4 gallons of latex added to each batch of grout, but we quickly discovered that with the additional solids provided by the 12% mix, the grout was thicker than desired. (The exact term used by the operators was "too snotty"). We trialed several latex ratios and found that 1 gallon of latex per 50 gallons of grout (2% by volume) provided the ideal pumping characteristics while lending the grout the needed tackiness.

Figure 1 – Latex Modified Grout

There are clear trade-offs in cost and in risk using latex-modified grout in laterals connected for sewer (LCS) grouting when using medium length lateral socks such as the 8' Logiball sock used at Sullivan's Island. Crews that utilized latex enhanced grout had no higher incidence of grout plugging than those that did not, but the difficulty of cleaning grout plugs from laterals was higher. Grout modified with latex (and glycol) is a requirement for pipes were very dry soil conditions, such as shallow laterals less than 3' deep, were encountered to prevent grout desiccation and pull-off (the loss of connection between the grout-soil mixture and the pipe exterior) during extended dry periods.

Latex costs ~$20 per gallon, so it adds about $0.40 per gallon to the cost of grout.

Benefit and cost of glycol as an anti-desiccant

Glycol replaces a portion of the water in the grout to help prevent desiccation during extended dry periods in pipes whose depth and soil type warrant it. The quantity of ethylene glycol added for every 50 gallons of grout is 2 gallons for pipe greater than 6' deep, 3 gallons for pipe between 4-6 feet deep, and 4 gallons for pipe between 3-4 feet deep, and 5 gallons for pipe less than 3 feet deep. If pipe is determined to be in soil that is nearly constantly moist (such as those at Sullivan's Island, where the groundwater table was less than 12" below grad), no ethylene glycol need be added. Ethylene glycol takes the place of the same volume of water normally added to the grout mix.

Grout refusal - correcting common engineering misperceptions

Most engineering specifications dictate that grout be pumped into a leaking joint/defect until "pump refusal". Most inspectors and engineers assume that this means the grout has set up and the grout pumps can no longer overcome the increased pressures rendered by the grout-soil matrix. While this is true in cases where the pipe is bedded directly in non-sandy packed soil, clayey soils, or flowable fill (i.e., where the opportunity to actually deliver grout is limited), in most cases the pipe is bedded in sand, crushed stone, or a sandy soil backfill and will readily take large amounts of grout if the pipe leaks. (As an aside, these are situations where grouting is likely to be of limited long term value, as grouting's effectiveness and longevity are directly related to delivering enough grout to surround the defect outside the pipe with grout).

Chemical pumps typically deliver grout at pressures between 40 and 90 psi at the packer port (depending on the grout rig's compressor or pump capabilities). Even the strongest grouts have an unconfined compressive strength less than 20 psi. In a confined environment, the grout can withstand higher pressures, but the grout pump is still generally capable of overcoming this via soil-grout fracturing, sending the additional grout into the pipe bedding. Because of this, step grouting should be used in all cases where sand or crushed stone bedding are used.

Where grout refusal is encountered, it was as likely to express itself as packer blow-by (i.e., when liquid grout squirts out from the packer) as actual grouted soil back pressure.

Packer inflation pressure vs. expansion pressure vs. contact pressure – understanding the significance of blow-by and of preventing unintended pipe fracturing

The packers used to test pipe and inject grout can be variably pressurized between 20-45 psi. It typically takes 15-20 psi of air pressure, depending on the age and manufacture of the packer, to simply overcome the material resistance of the rubber and inflate the packer outward (expansion pressure). Assuming a 20 psi inflation requirement for packer inflation, and a 30 psi gauge pressure, the contact pressure (i.e, the actual pressure holding the packer against the inside of the pipe wall and preventing grout blow-by) is only 10 psi. Many grout operators set their packer pressure at 45 psi, or a 20-30 psi contact pressure. This results in a tight seal that minimizes blow-by. However, old clay pipe can have latent, non-visible or easily missed defects that cause the pipe to crack under these pressures. This is most likely in soils prone to void generation during bedding wash-in from groundwater leakage, such as non-sandy fill materials. It is less likely to occur in pipes bedded in crushed stone or sand, which tends to drop down into the void and maintain contact with the pipe (often at the expense of sinkholes in the overlying pavement. To minimize cracking while preventing excessive blow-by, we found a 15 psi contact pressure generally worked best. If pipe cracking continues, lowering the contact pressure to 10-12 psi may help. Establishing the packer inflation pressure corresponding to this requires a packer test to determine packer inflation pressure. As packer inflation pressure changes with time and use, we recommend this test be conducted weekly.

Liquid phase dilution of grout

As the liquid, non-gelled grout is pumped into the pipe bedding, during saturated ground conditions it comes into intimate contact with groundwater. We conducted several tests using latex-modified grout pumped into a pipe filled with groundwater. We found that the grout does not mix with the water, but rather displaces the water and retains its typical characteristics. This eliminated most concerns regarding groundwater dilution of grout concentration.

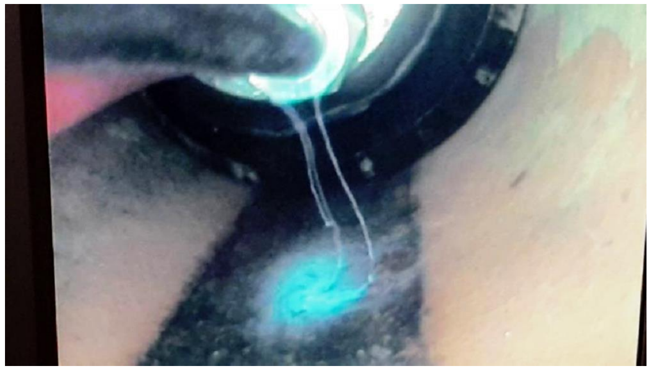

Figure 2 – Grout Displacing Water in Flooded Pipe

Grout gel time calculations and safety factor to accommodate the difference between desk assumptions and field conditions

Gel time is set to accommodate both the packer void space and the amount of grout desired to be placed outside the pipe. It is a primarily a function of grout pump rate. Pump rate is field determined with the packer removed. The additional friction loss from packer ports, defect restrictions, soil void space restrictions, and the hydrostatic groundwater backpressure reduce the actual delivered flow rate significantly. This reduction in delivered flow rate needs to be considered when establishing gel time. We recommend a starting gel time that is 20% higher than indicated by base pump rates, then adjusting the gel time as in situ pumping rates are measured.

Short gel times versus long gel times – the pros and cons

The liquid, not-yet-gelled grout needs to infuse the pipe bedding before gelling to form an effective seal. The longer the grout takes to set, the more time it has to permeate the bedding, displace water in the bedding void space, and form a large mass around the leaking defect. Gel time (the period it takes the liquid grout to transform to a semisolid form) is calculated using a number of variables to allow this to occur, and should accommodate both the packer void space and the amount of grout desired to be placed outside the pipe. It is a primarily a function of grout pump rate. At a typical pump rate of 4 gpm, gel times for MLJs are approximately 40 seconds for 8" pipe and 90 seconds for 8' LCS socks on 6" laterals. This is significantly longer than the typical convention of 15-20 second gel time regardless of conditions, packers, pumps, or leakage reduction goals. The benefit of long

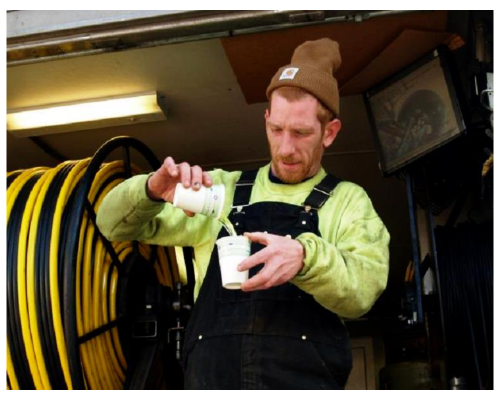

Figure 3 – Checking Gel Time

gel time is more grout can be infused into the surrounding bedding, resulting in lower leakage and in longer lasting leakage reductions.

The downside to these long gel times is it takes longer to grout and cost more money. As you must wait a full gel cycle before retesting a grouted joint, you effectively double the time it takes to grout a joint. In situations where groundwater is actively running or gushing through defects not covered by the packer, the grouts simply flows back into the pipe without gelling in the soil. In this case, the gel time should be shortened to meet the field conditions by adding catalyst to the grout. Very long gel times are indicated when using long sock fracture grouting (LSFG), lateral cleanout-launch grouting (LCOG) with very long socks, very long LCS socks, or for pipe diameters greater than 18". However, we have found that the percentage of catalysts needed to achieve gel time greater than 3 minutes is so low as to stoichiometric ally challenge the grout reaction, resulting in highly inconsistent gel times when repeatedly checked. We recommend utilizing grout pumps and packer ports sized to deliver grout sufficiently fast to keep gel times under 2 minutes whenever possible.

The impact of mixing on gel time

Grout tanks should be mixed hourly for 2 minutes to ensure no solids settle (especially the dichlobenil). We found that when gel time were checked immediately after mixing, the varying levels of air introduced into the tanks made reliably setting gel time difficult. We found that mixers should be turned off and the tanks allowed to quiet for at 10 minutes before attempting to check gel time.

The impact on gel time from the often unrecognized endothermic reactions resulting from mixing acrylamide with water

Specifications require gel time to be check and adjusted as each batch of grout is made. However, there is a strong endothermic reaction (meaning the temperature of the grout drops) when acrylamide is mixed with water in the A Tank. Typical temperature difference between the A Tank and the B Tank immediately after initial mixing is 15°F. When the makeup water has a temperature of less than 45°F, ice chips will actually form in the A Tank.

Grout temperature strongly affects gel time. For every 10°F increase in grout temperature, gel time is cut in half. Therefore, this 15°F temperature difference between the A Tank and the B Tank significantly affects the gel time. As the A Tank warms, the gel time is reduced, often by a factor of 40%. The rate of warming is a function of ambient temperature.

To minimize the impact of this condition, we recommend the acrylamide and water be added to the A Tank the evening before work and at each lunch/work break to allow temperature equalization to take place before adjusting gel set time.

Impacts on gel time when mixing the two catalysts in even and uneven stoichiometric ratios

Acrylamide grouts are catalyzed using a two part catalyst system. Cat T (Avanti's AV-101) is an activator added to the A Tank. The second catalyst, variably called Salt, AP, or SP, is added to B Tank (the catalyst tank) as the polymerization initiator. Both chemicals are manufactured to be mixed in equal weights to achieve a balance stoichiometry. When mixed this way, they generally present reliable gel times. However, gel times are difficult to predict when these two chemicals are not mixed in balance, and the gel time is often unstable when checked repeatedly. We recommend a scale be used to accurately weigh out these chemicals (both solids and liquids) for each batch to produce reliable, repeatable gel times. Initiator-deficient grouts can also lead to popcorn polymerization, especially in low oxygen water with residual concentrations of KFe. We recommend additional bench scale test be conducted to determine the impact of more and of less catalysts on gel time at various tank temperatures. We recommend additional bench scale work be done to determine the impact of unbalanced catalysts on gel time and grout strength.

Lowering gel time without decreasing acrylamide concentration – dilution of ammonium persulfate catalyst

If a grout batch is found to have too short a gel time, potassium ferricyanide (KFe) can be used to extend the gel time. However, adjusting gel time with KFe is difficult as only a small amount can often extend the grout to unusably long gel time, requiring further catalyst additions and wasting time and materials. Adding water to B Tank is an acceptable alternative, as all it does not affect the percent solids in the grout (provided exclusively from A Tank). It does introduce a less reliable gel time (as described in the preceding paragraph), but is often easier, faster, and cheaper to do than a KFe addition. In no case should additional water be added to the A Tank. We also recommend cutting or mixing the standard KFe powder with filler to so the gel time is less sensitive to the addition of a few more grams of KFE.

Veneering versus long term sealing - Minimum grout per joint goals, and how to achieve them via extended gel times and step grouting, and when does grout volume become excessive

Less than 0.5 gallons of grout will often seal a leaking joint --- temporarily. However, as an 8" mainline joint packer has a void space of 0.3 gallons, effectively all you are doing is caulking the inside of the joint with the remaining 0.2 gallons of grout. This condition is known as veneering. Hydrostatic pressures will soon push that grout out, allowing leakage to continue again. The air test itself can actually increase leakage in these situations by clearing the joint of sediment and mineral deposits and increasing groundwater pathways to the joint.

As the goal is to get a large amount of grout through the defect to the outside of the pipe where it can mix with the pipe bedding to form a tight, strong seal where groundwater pushes the soil-grout seal tighter against the pipe, veneering is not desirable. ASTM F2304-10 suggests a rate of 0.5 gallons of grout per inch diameter of pipe (4 gallons of grout for an 8" pipe). NASSCO guidelines expect a grout acceptance rate of 0.25 gallons per inch diameter (2 gallons of grout for an 8" pipe).

At Sullivan's Island, where the beach sands were capable of taking huge amounts of grout and the phenomenon of grout piping (where grout follows a preferential soil fracture away from the joint), necessitating a more conservative grout volume basis for sealing, step grouting became imperative. For mainline joints, we found that a step grout process of pumping 3 gallons of grout, followed by a 1 minute wait period, then a retest worked best. If the joint failed this second test, we pumped 2 more gallons, then repeated the wait and test cycle. If the joint failed this third test, we pumped 2 more gallons and declared the joint sealed as best it could be. We call this a 3-5-7 step grout. Using this method, we averaged 3.4 gallons of grout per mainline joint (MLJ). Where we conducted lateral connect to sewer (LCS) grouting using 8' long sock on the 6" laterals, we employed a 5-7-9 step grout to account for the greater annular space and the multiple joints being sealed simultaneously. Using this method, we averaged 5.4 gallons of grout per LCS.

Old grout gelling in tanks and hoses

Several times during the project, grout rigs were left unused for several days. When then grout hoses were not blown out with air and/or filled with clean water, the grout in the line solidified 1 in 3 times. We also found that grout left for several days becomes oxygen deficient. When this grout has an initiator-deficient condition (which can readily happen with long gel time grouts), especially when co-present with residual concentrations of KFe, can lead to popcorn polymerization.

Figure 4 – Popcorn Grout

Impact of grout pump rate in sand and crushed stone pipe beddings on production

Grout rigs using air driven pumps typically provide between 2-5 gpm of delivered grout to a mainline packer. Pump rate is dependent on the length and condition of hose on the reel, compressor, and pump/diaphragm. In high void space bedding materials like sand and crushed stone that readily took 3 gallons of grout, pumping each joint took up to a full minute for each mainline joint. For LCS grouting, it took up to 5 minutes to pump the minimum volume of grout. Having pumps that can deliver 5 gpm were markedly more productive than those that only delivered 3 gpm. In high joint failure pipe (Sullivan's Island had a mainline joint failure rate of 38% and an LCS failure rate of 86%), the faster pumps improved average daily production by approximately 10%.

Pump rate test and packer integrity test frequencies based on job site findings

The specifications at the start of the job required packer integrity testing and pump rate and balance testing be conducted daily. After two weeks, field results for 3 grout rigs showed little change day to day, and these requirements were reduced to twice weekly. After two months, little change was seen in the packer integrity test week to week, and its requirement was changed to weekly. The specifications remained at twice weekly for these two tests for the older grout rigs whose equipment have been shown to be less reliable.

Figure 5 – Pump Rate Test

How to quickly adjust gel time when active leakage is preventing grout set-up
Long gel set time foster good grouting, but when leakage into the pipe from defects adjacent to the one being grouted cause grout washout before gel, gel times must be reduced. This can be readily accomplished by adding additional appropriate catalysts in even measure into both the A Tank and the B Tank, retesting for gel time, and adjusting to first 20 second gel time, trying grouting again, and if need be further reducing gel set time if washout continue to occur.

Contingency rules for when a pipe fractures from packer pressures
Occasionally during testing or grouting, the pipe will crack, fracture, or break. When this happens, it is imperative that the operator immediately reinflate the packer to prevent collapse and pipe bedding wash-in. Once the packer is reinflated, the gel set time should be immediately lowered to 10-15 seconds using the process described above. This grout should be pumped into the fractured pipe to stabilize the fractures, solidify the pipe bedding, and "glue" the pipe to the pipe bedding. Grout should be pumped until the defect stays in place when the packer is deflated. If the cracks/fractures extend beyond the packer area, the packer should be moved, inflated to minimum packer inflation pressure (i.e., to place as little stress on the pipe as possible) and additional grout pumped.

Impact of double batching grout on production
In a high failure rate and/or high grout per failure situation like experienced at Sullivan's Island, significant production time is lost in making batches of grout. A typical 220' long section of pipe with 5' joint spacing yields 44 joints and 5 laterals. With a 38% MLJ failure rate and a 3.4 gallon per joint average grout rate, and with an 86% LCS failure rate and a 5.4 gallon per lateral average grout rate, each segment of pipe averages 80 gallons of grout. The rigs with 60 gallon tanks had to make grout half as often as those with 30 gallon tanks. On average, this added 30 minute per day of productive test and seal time to the rigs able to double batch, a 5% increase in production.

Lateral grouting from cleanouts (LCOG)
While all of the LCSs were grouted from the mainline using 8' long Logiball socks, significant portions of the lateral remained ungrouted -- and therefore prone to leakage. Many of these laterals were routed directly (typically ~6") under open storm water swales and storm water pipes installed soil-tight rather than watertight. Fortunately, many of the laterals had cleanouts at the property line. Where these cleanouts were on sweeps or 6" tees, we were able to use specially modified flexible packers to test and seal the leaking lateral joints from the cleanout to the LCS termination joint. To pull as well as push this packer, vacuum-pulled parachutes were sucked from the manhole to the lateral to the cleanout

Figure 6 – Lateral Under Water-filled Storm water Swale

Figure 7 – LCOG Parachute

with a pilot string. A cable was attached and fed back to the manhole, attached to the lead edge of the LCOG packer, and used to pull the packer from the cleanout to the tap. This LCOG work eliminated significant leakage from these laterals, especially rainfall induced infiltration entering these shallow laterals during the peak of the storm. This technology is 10-25% the cost of lateral lining.

Figure 8 - LCOG Packer

Long Sock Fracture Grouting (LSFG)

Many segments had circumferential cracks and fractures, which when treated like joints are readily sealed with a mainline packer. However, some segments had longitudinal and multiple cracks and fractures. To address these, a new technology, called long sock fracture grouting, or LSFG, was developed. Two types of LSFG packers were developed to address two types of conditions. The first packer is used when the fracture covers more than 2' of the pipe section. It spans both joints on either side of the longitudinal fracture, grouting both mainline joints as well as the fractures in between. This version of the long sock is 11' long for the 5' joint spacing. The second packer is used when the defects cover less than 2' of the pipe segment. It is 5' long. Long sock grouting reduces and often eliminates all leakage through the longitudinal or multiple fracture, prevents further pipe bedding loss, provide a large pipe bed trench dam to minimize trenchwater migration, and stabilizes the defect so that it deteriorates at a much slower rate. This technology is not particularly effective on cracks, as these defects are too tight to allow adequate volumes of grout to move to the outside of the pipe. Of the nearly 100 fractures grouted using LSFG, none resulted in collapsed pipe. This technology is 33% the cost of a cured in place point repair.

Figure 9 – Long Sock Fracture Grouting

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