The Test Cell Grouting Research White Paper

Version: 1.0
May 2023

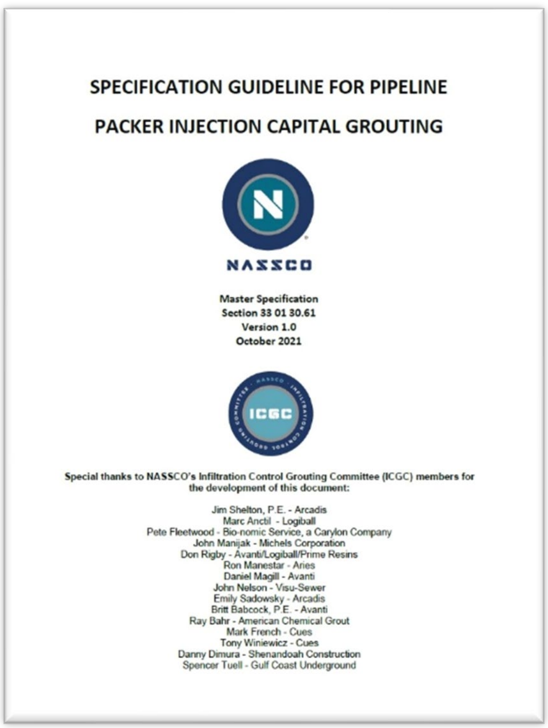
Special thanks to NASSCO's Infiltration Control Grouting Committee (ICGC) and the following individuals for the development of this document:

John Manijak – Hoerr Construction, Inc.
Ray Bahr, PE – American Chemical Grout Company
James Shelton, PE – Arcadis
Marc Anctil – Logiball
Britt Babcock, PE – Avanti International
Pete Fleetwood – Bionomics
Ron Manestar – Aries
Don Rigby – Madewell
Mark Webb, PhD, PE – AECOM
Jessica Williams – Avanti International
Mark Schneider – CUES

Disclaimer

This document was prepared by Committees comprised of representatives of NASSCO members and peer-reviewed by industry professionals. The content contained herein is not specific to any one product, project, or job site, and should be considered a guideline only. Conditions for use may require additions, deletions, or amendments to this document so as to conform to project-specific site conditions and to comply with applicable laws, regulations, and ordinances. NASSCO does not guarantee, certify, or assure any result and assumes no liability as to content, use and application of this document.

Introduction: In 2016, a group of engineers, contractors and vendors began working on an update to the NASSCO packer injection grouting technical specifications. It was recognized that recent practices in chemical grouting, called Capital Grouting had achieved significant long-term reductions in infiltration. These results were documented via independently conducted studies. The changes in tools, practices and procedures were based on an understanding of how the grout in situ was achieving long-term seals. These results were backed up by several studies conducted using pre and post rehabilitation control-based procedures to determine that not only was long term infiltration elimination effective but remained effective for over a decade. The group's objective was to update the NASSCO packer injection grouting technical specifications to incorporate the Capital Grouting techniques and to differentiate them from the traditional, short term or pre-rehabilitation grouting methodologies. While developing these specifications several questions arose that necessitated scientific investigations. To confirm/prove the underlying reasons that capital grouting was so effective over such a long period of time, this team identified the need to design a full-scale test. The conception of the Test Cell Study was initiated because of the recognition that significant changes in the understanding of how chemical grout works to seal out pipe leakage, especially long term, had been achieved; in prior decades. It was decided in 2016 that a test cell would be constructed of suitable dimensions that would allow an independent testing team to trial different types of grouting practices, exhume the resulting grout masses, and assess what was going on outside the structure. This work was done specifically to guide the developing specification, the technical manual, and the engineer and inspector certification training program. This white paper documents the results of the test cell findings and the conclusions that resulted. The following White Paper refers to the eight different tests that were conducted and includes many photographs to illustrate the findings to collaborate the results and conclusions. All test results were reviewed in two separate meetings that took place in Chicago (2017) and New Orleans (2018) during WEFTEC and subsequent periods in 2019. The team of reviewers for these results included contractors, independent engineers, and material suppliers. The two sessions were held to allow for sufficient time between the two sessions to enhance the confidence level of the conclusions that were reached. Over a series of bi-monthly meetings beginning in September 2021, the ICGC Test Cell Workgroup analyzed the observations and findings to assemble this White Paper. This paper documents the results of the test cell findings and the conclusions that resulted from the tests.


SPECIFICATION GUIDELINE FOR PIPELINE

PACKER INJECTION CAPITAL GROUTING

NASSCO

Master Specification
Section 33 01 30.61
Version 1.0
October 2021

Special thanks to NASSCO's Infiltration Control Grouting Committee (ICGC) members for the development of this document:

Jim Shelton, P.E. - Arcadis
Marc Anctil - Logiball
Pete Fleetwood - Bio-nomic Service, a Carylon Company
John Manijak - Michels Corporation
Don Rigby - Avanti/Logiball/Prime Resins
Ron Manestar - Aries
Daniel Magill - Avanti
John Nelson - Visu-Sewer
Emily Sadowsky - Arcadis
Britt Babcock, P.E. - Avanti
Ray Bahr - American Chemical Grout
Mark French - Cues
Tony Winiewicz - Cues
Danny Dimura - Shenandoah Construction
Spencer Tuell - Gulf Coast Underground

The objectives of this Test Cell Study were to support the development of the new NASSCO master specifications, the technical manual, and the engineering inspector certification program. The test cell study was developed so that several grouting concepts could be tested specific to how grout behaves under a variety of gel times and pumping rates while conducted in a variety of pipe bedding conditions.

Figure: 1: Test Cell Study Members

Financial support for this work was provided by Arcadis, Aries, Avanti International, Bio-Nomic Services, Great Lakes TV Seal, Lake County Sewer, Logiball, Shenandoah Construction and Visu-Sewer. Financial support included donations of materials, money, time, and technical expertise.

The investigation was led by Jim Shelton, PE from Arcadis. Bio-Nomics Services built the test cell and provided most of the labor and equipment that was used to construct the eight different test cell trials that were done. Staff from Logiball, Avanti, and Aries, also played significant roles in the labor and technical resources used in constructing these cells. Testing took place over the course of three different periods in 2016 and 2017. Each test cell took about a day to construct and deconstruct.

Figure: 2: Test Cell Study Team Members

The test cell program was intended to evaluate the variables that go into how grout is applied via packer injection grouting, and to assess the resulting formations using a set of variables and evaluation criteria:

The variables included:
- Pumping rates
- Gel times
- Step grouting practices
- Soil types or pipe beddings

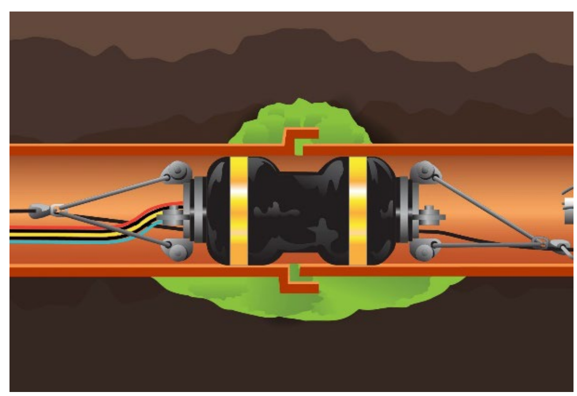


Figure: 3: Mainline Packer Grouting Joint

The evaluation criteria included:
- The shape and formation of the grout mass
- The strength or the cohesion of the grout mass, both above and below the pipe upon excavation

To determine if the grout achieved a seal at the defect the following were documented:
- Testing procedures using packer method positive air test
- The dissection of the grouted mass or gel/soil matrix
- The shape and volume of the grout seal surrounding the defect.

This was done by assessing the impact of the grouting variables to assess where the grout was placed to provide the best long-term results in sealing the actual defect, stabilizing the pipe, and providing a trench dam to reduce trench water migration.

Test Cell Construction Procedures:

The full-size Test Cell was constructed of steel with bolted panels to allow access for construction and disassembly of the test cell. The dimensions of the Test Cell were ten feet long by six and a half feet high by four feet wide. The Test Cell was also constructed with holes for pipe penetrations through the long ends that allowed a close fit for an eight inch outside diameter vitrified clay pipe. It was also fitted with drain holes at the bottom that would allow for an evaluation of the amount of water that might pass through the test cell structure after it was filled.

Figure: 4: Test Cell During Construction

Common and identical construction practices were used throughout all the grouting tests. The test cell was filled about halfway with compacted native North Carolina clean neat red clay. This material was selected because of its low permeability and ability to hold form (i.e., due to cohesion) allowing a trench to be excavated with vertical sides reducing the overall Test Cell width. The clay was placed moist and compacted in eight-inch lifts, to a depth of two and a half

Figure 5: Trench Install

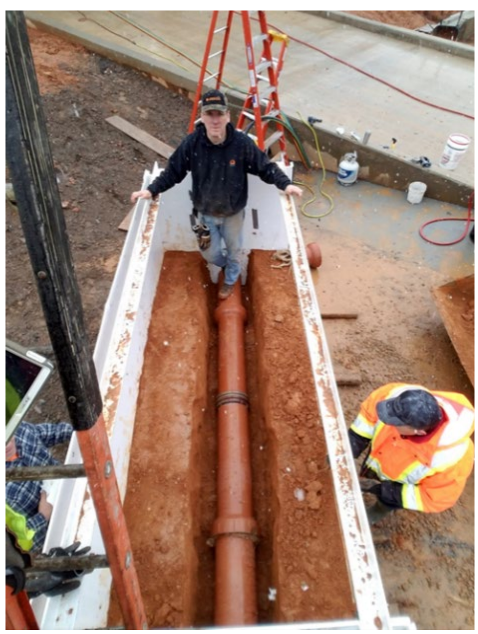


Figure 6: Pipe Install with Defects

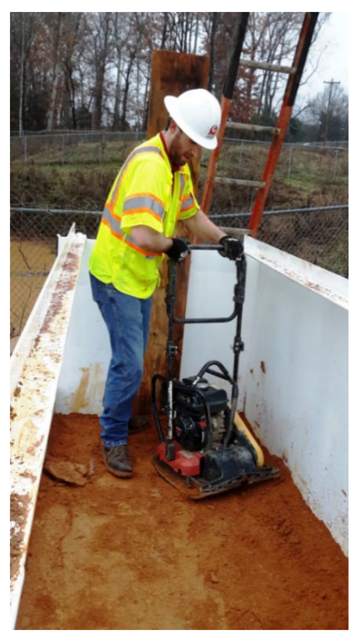


Figure 7: Soil Cover Compaction

feet. A hand-excavated 22-inch wide by 26-inch-deep trench was installed through the middle of the compacted clay to mimic a trench in the native soils. The bottom of the trench was then hand tamped to mimic undisturbed sub-trench soils. The dimensions of the trench allowed for the installation of four inches of pipe bedding under the invert of the pipe, eight inches on both sides, and four to six inches over the crown of the pipe.

Once the trench was excavated, the selected pipe bedding was placed as a four-inch lift inside the trench. The bell holes were cleared for the two segments of pipe that were placed in the middle of the trench, with the female ends facing out and the male ends of the pipes butted together and filled with oakum. This male-male mimicked a circumferential fracture / fully open joint (Figure 10) – commonly found in many pipes. This was labeled Joint "B" – or Defect "B". Two additional pipes were then inserted through the holes at the ends of each side of the box with the spigot end first and then pushed into the outward facing female bell ends.[1]

The two additional pipes were then connected to the female ends of the middle pipe and sealed with a hydraulic cement. A single point was left open recreating a joint defect in each of them. The openings or defects were the size of a screwdriver width – less than one square inch opening.

Figure 8: Pipe Defects Recreated Prior To Backfill

Figure 9: Defect C - 12 o'clock Position

Figure 10: Defect B - Full Circumferential

Figure 11: Defect Partial Burial

For Joint "A" – the Defect "A" was placed at the 3 o'clock or spring line position and for Joint "C" – the Defect "C" was placed at the 12 o'clock position (Figure 9).

The remainder of the pipe bedding was then placed around the pipe to the spring line. It was tamped in by foot, not shove sliced. This was to mimic conditions that are commonly seen in past clay pipe installations. The pipe was then photographed as it was bedded to the spring line. After that additional bedding material was added in two more loose lifts about six inches each, and then hand tamped until six inches of material was placed above the crown of the pipe. At that point, the alignment was checked from the outside of the test cell making sure nothing had been disturbed or broken. The entire bedding was then saturated until water was observed entering the pipe defects. Any water that remained in the trench was meant to remain, mimicking the movement of rainwater or ground water along utility and sewer trenches[2].

Figure 12: Hand Tamping

After recreating the pipe installation, the balance of the cell was filled at 12-inch lifts using red North Carolina clay. The 12-inch lifts were compacted using a combination of a rammer compactor ("Jumping Jack") and hand tamps, then sprinkled with water to provide a tight fit. With the test cell filled completely, the entire surface of the test cell was saturated with water. After 20 minutes, the surface was tamped again. Upon completion of this step, a full four and a half feet of backfill material had been placed over the pipe. This practice was modified for the second half of the tests; instead of filling the test cell to the top with clay, only two and a half feet of clay was placed on top of the pipe bed (for soil cover) then plywood plates with sand

Figure 13: Saturating Full Installation

Figure 14: Super Sacks Used to Recreate Typical Soil Loading

filled super-sacks were placed on top. This method was quicker to install and disassemble while still recreating typical soil loads on top of the pipe (Figure 14).

Grouting Procedure:

Once the Test Cell construction was completed, the first grout tests were performed following general packer grouting procedures. The procedures were only modified slightly for each of the different tests. Each of the chemical grout mixture specifics were documented. A 12% acrylamide grout mixture was used for every one of the tests. This mixture meets the current NASSCO recommendation for grout percentage using a 95%-5% acrylamide / MBA grout mixture[3,4] – also known as 95/5. For every test with exception of the first two tests, 1.5% latex by total batch volume was added. Latex is a common additive providing strength to the final grout structure. Acrylamide grout was specifically used which has a low initial viscosity until the very end of the gelling stage at which point it sets rapidly. These grouts have initial viscosities close to that of water (1 cP) and can penetrate formations with a coefficient of permeability as low as 10^{-4} cm/sec[5].

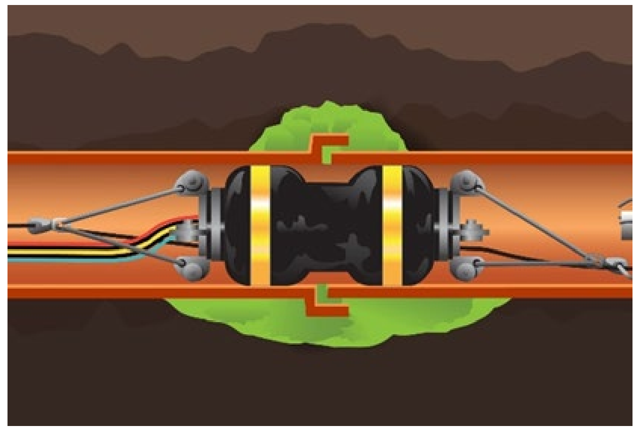


Figure 15: Packer Injection Grouting

After the grout mixture was properly prepared and the gel times adjusted to the target time, a main line joint packer was inserted into the pipe. In every test study, the joints were grouted in the following sequence: Joint “A”, which was the three o'clock defect (right side all photos). Joint “C”, which was the twelve o'clock defect (left side all photos), and then Joint “B”, which was the circumferential fracture (center of the test cell). After sealing, the joints were tested at four psi in accordance with the NASSCO testing specification. The grout was pumped until the pressure gauge indicated a sharp increase in void space pressure (refusal). If refusal was not achieved with 2.5 gallons of grout, then step grouting was performed incrementally by pumping an additional two gallons of grout, depending upon the reaction of the void space pressure monitor.

Figure 16: Superior Plate of Test Cell Removed After Grouting

It was observed that in some instances more than three and a half gallons of grout was pumped into joint “C”. The defects were injected in one-gallon increments. This was to determine if there was a difference in the way the grout was delivered after the initial injection, either pumping to the maximum allotted amount or until refusal, meaning that the joint was sealed.

Disassembly: After grouting, the test cell was disassembled by removing the surface plates, weights, and the backfill over the pipe embedment using an excavator bucket to a level

Figure 17: Removal of Backfill

approximately one foot from the top of the pipe. The front plate was constructed in two parts so that it could be removed in increments.

After nearing the pipe bedding, the backfill was then hand excavated until the grout masses were revealed. The work took place slowly and gently, and primarily utilized hand trowels and small garden spades to leave the grout matrix undisturbed.

Formation Reveal Procedures:
After the general grout outline around each of the three defects was determined and photographed, a garden hose was used with low water pressure to wash away any loose materials. This revealed what had been grouted or not each step of the way. After documenting the grout shapes and masses, each grout matrix was then dissected to determine the internal forms.

Figure 18: Water Used to Remove Loose Material

Eight total tests were conducted as part of this work:

- Test 1 & 2: Colored Grout Injection
    - To evaluate where the grout travels at various stages of pumping.
- Test 3 & 4: Sand Bedding Material
- Test 5 & 6: Stone Bedding Material
- Test 7 & 8: Clay Bedding Material

Each of the tests used different gel times to evaluate how gel times impacted the shapes and distributions of grout in the various pipe bedding materials.

Colored Grout Injection Tests 1 & 2

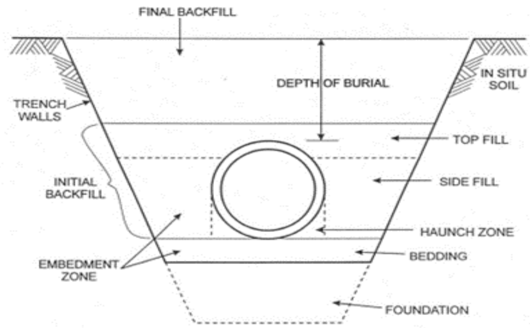


Figure 19: Diagram of Pipe Installation

The goals of the initial injection trials were to answer two questions:

1. Where did the grout travel given the different pumping increments?
2. How was the grout mass affected if the grout was given a different gel time?

This was accomplished by observing where the first, second, and third increments of injected grout solidified as they were pumped into the *embedment zone (bedding and initial backfill)*. This was achieved by using different color dyes in the grout increments that were injected.

Tests 1 and 2 were completed in sand bedding, using a three-gallon per minute (gpm) pumping rate and 20-second and 55-second gel times respectively. The different colored grouts were pumped in sequential increments using red, then blue, and then yellow dye.

Figure 20: Colored Grouted Formation First Revealed

Test 1 – 20 Second Gel Time
For Test 1, the gel time was set at 20 seconds while using a pumping rate of three gpm. We were able to pump 2.0, 1.5, and 1.6 gallons of grout respectively into each of the defects (A, B, & C). All three joints passed the air test.

Test #1 - Sand, Colored Grout, 20 Second Gel Time

A Defect - 3 O'Clock Position	B Defect - Circumferencial	C Defect - 12 O'Clock Position
1 Pump Red Grout	1 Pump Red Grout	1 Pump Red Grout
2 0.5g, VP=10 psi	2 0.5g, VP=2psi	2 05.g, VP=6psi
3 Pump to 1.25g, VP=0 psi once pumps turned off	3 Pump to 1.25g, VP=3psi, then drops to 0	3 Pump to 1.25g, VP=6psi then drops to 0
4 Change to Blue Dye	4 Change to Blue Dye	4 Change to Blue Dye
5 Test - VP=4psi, drops to 3 psi in 10 secs.	5 Test. Pass at 9psi	5 Test and Fail, Pump to 1.6g. VP>20psi, slowly drops
6 Pump Blue. VP=15, Blowby at 1.35g	6 Pump to 1.5g, Blowby	6 Deflate and wait - Test and Pass at 14psi
7 Wait 30 secs, Test at 9 psi, drops to 8 psi < 15 secs	7 Test and Pass	7 Stop Test
8 Pump to 2g, Blowby	8 Stop Test	
9 Deflate, Test and Pass at 7 psi		
10 Stop Test		

When using the 20 second gel time, the goal of pumping 3.5 gallons was not achieved because the fast gel time resulted in the grout quickly hardening and spiking void pressures before the grout volume goals could be achieved. Only two grouting increments were able to be completed. As observed, a donut shaped gel/soil mass was found and there was very little grout migration or cradling support under the pipe.

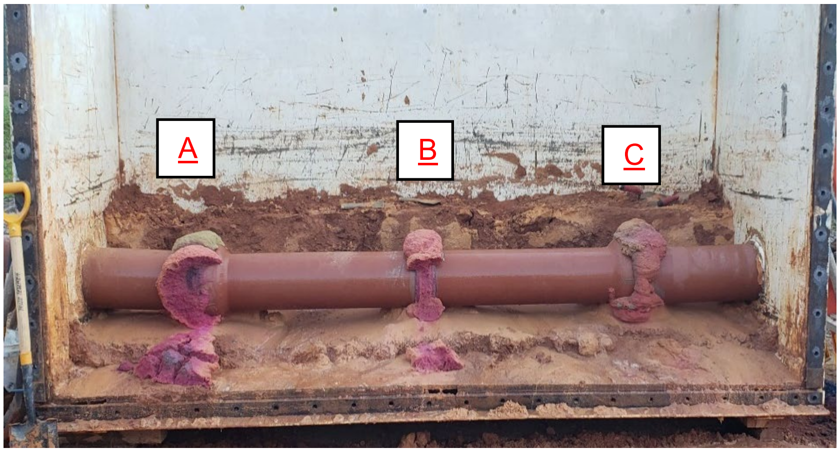


Figure 21: Grout Formations Observed After Removal of Loose Bedding

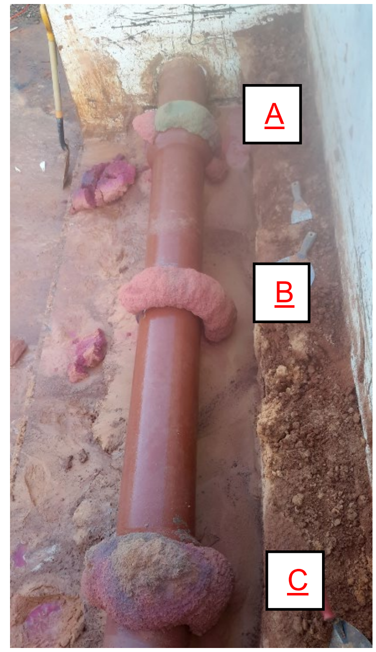


Figure 22: Top View of Grout Formation

The relatively small grout masses were generally weak and minimally supported, falling apart easily once the pipe bedding shifted.

Defect A Observations – 20 Seconds Gel Time

At Defect A located at the 3 o'clock position, the red grout, which was the first grout pumped, traveled the furthest from the defect. Because the gel time was at 20 seconds, the red grout

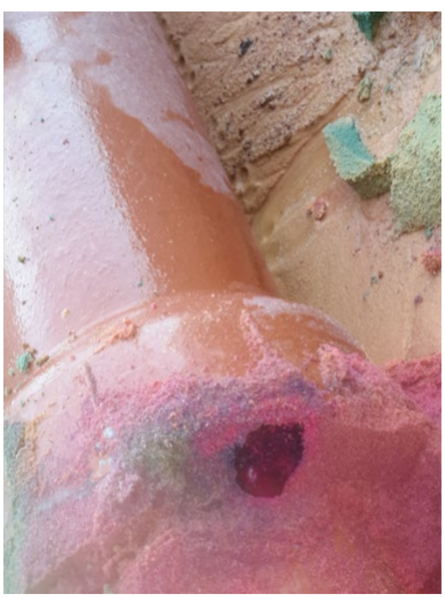


Figure 23: Neat Grout Located Outside Defect A

Figure 24: 2 Distinct Colors Observed at Defect A

Figures 25 & 26: Defect A Observation

composed most of the actual pipe defect sealing material. At the actual location of 3 o'clock defect the seal was primarily red grout with very little soil mixture (Figure 23). The second stage of blue grout broke out through the original neat red grout plug (Figures 24, 25, 26) and moved toward the top of the pipe as a separate mass. (Grout on top of the pipe is of very limited value for pipe stabilization.)

Defect A Dissection:
The blue grout broke through the red grout and followed a separate path, creating its own mass. This is theorized as a function of step grouting since this formation may not have occurred if the initial red grout was continuously pumped to refusal.

Figures 27, 28, 29, 30: Dissection of Defect A Grout Mass

Figure 31: Observation of Distinct Paths of Red and Blue Dyed Grouts

Defect B Observations – 20 Second Gel Time
The grout formation that was located around the circumferential fracture at Defect B appeared to have fully encompassed the structure.

Figure 32: Defect B Grout Formation

Figure 33: Defect B Formation Top View

Figure 34: Defect B Side View

Defect B – Dissection:

While this defect was a full circumferential fracture, only 1.25 gallons of red grout and 0.15 gallons of blue grout were able to be pumped before blow-by of the packer (void space over pressurization) occurred. When dissected, all the grout formations close to the pipe were red in color, and blue grout was again on top of the pipe, with very little grout supporting the underside of the pipe.

Figure 35: Defect B Dissection

Figure 36: Defect B Dissection

Figure 37: Defect B Removal of Top Seal

Defect C Observations – 20 Second Gel Time

At Defect C located at the 12 o'clock position, 1.55 gallons of red grout were pumped first, then only 0.35 gallons of blue grout were pumped before refusal was achieved. The grout came out

Figure 38: Defect C Seal Side View

Figure 39: Defect C Seal Top View

of the top of the pipe as expected based on the defect orientation. Most of the grout resided just outside of the defect with minimal grout travel around the sides of the pipe and settling at the bottom or invert of the pipe. The fast gel time limited the ability of the liquid grout to migrate below the pipe providing very little pipe stabilization.

Defect C Dissection:

When the mass was dissected, the interior of the seal was primarily the initial red grout around the defect. The small amount of blue grout pumped remained close to the pipe joint defect.

Figure 40: Defect C Dissection

Figure 41: Defect C Dissection Side View

Figure 42: Defect C Neat Grout Seal Exposed

Test 2 – 55 Second Gel Time

During Test 2, the gel time was extended to 55 seconds while still using the same pumping rate as the Test 1. We were able to pump 2.3, 2.9, and 2.1 gallons of grout respectively into each of the defects (A, B, & C). All three joints passed the air test.

Test #2 - Sand, Colored Grout, 55 Second Gel Time

	A Defect - 3 O'clock Position		B Defect - Circumferential		C Defect - 12 O'clock Position
1	Pump Red Grout	1	Pump Red Grout	1	Pump Red Grout
2	0.5g, VP=10 psi	2	0.5g, VP=2psi	2	0.6g, VP = 5 psi, drops to 3 psi
3	Pump to 1.25g, VP=0 psi after pumps turned off.	3	Pump to 1.25g, VP = 0 psi when pump turned off.	3	Pump to 1.25g, VP = 0 when pump turned off.
4	Wait 60 sec. Test and Fail	4	Wait 60 sec. Test and Fail	4	Wait 120 sec. Test and Fail
5	Change to Blue Dye	5	Change to Blue Dye	5	Change to Blue Dye
6	Test. VP = 0 psi	6	Test. VP = 0 psi	6	Test. VP = 0 psi
7	Pump Blue to 1.4-gal, VP = 15 psi, drops to 9 psi.	7	Pump Blue to 1.3-gal, VP = 7 psi, Pump to 2.1 gal.	7	Pump Blue to 1.3-gal, VP = 12 psi, Pump to 2.1 gal
8	Pump to 2.1 gal, Wait 60 seconds. Jus to 10 psi, drops to 9 psi.	8	Wait 60 seconds. Test and Fail.	8	Wait 60 seconds. Test at 9 psi dropping very slowly.
9	Change to Yellow Dye	9	Change to Yellow Dye	9	Change to Yellow Dye
10	Test at 5.5 psi, drops to 4.5 in 20 sec. Test at 7 psi - Fail	10	Test and Fail.	10	Test and Pass at 9 psi
11	Start Pump - VP>15 psi immed., blowby at 2.3 gal.	11	Start Pump - VP>15 psi immed., blowby at 2.2 gal.	11	Stop Test
12	Deflate, Test and Pass at 13 psi	12	Wait 90 sec. Test and Fail		
13	Stop Test	13	Step grout at 0.1 inc. to 2.9g, VP>15 psi.		
		14	Wait 2 min. Test and Pass at 17 psi		
		15	Stop Test		

Defect B (Circumferential): Observation and Dissection:
Dissection of the grout confirmed that the red grout immediately migrated below the pipe (Figure 43), providing the cradling of the invert. The blue grout pumped second - filled the areas near the pipe joint defect. Finally, the yellow grout – pumped last, fracked through the blue mass, turned green, and established a mass above the pipe (Figure 45).

Figure 43: Red Grout Observed Below Pipe

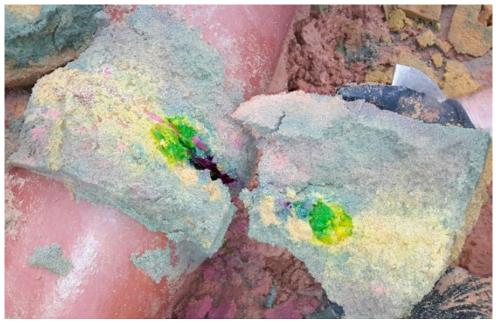


Figure 44: Green Grout Observed Surrounding Defect

Figure 45: Yellow and Green Grout Observed Above Pipe

Defect C Observations – 55 second gel time.
Defect C was located at the 12 o'clock position. With a 55 second gel time, the red grout migrated below the pipe.

Figure 46: Dissection of Defect C

Figure 47: Side Dissection

Figure 48: Top View of Mass

Defect C: Dissection
The grouted mass was filled with a combination of red and blue grout. The lower gel/soil matrix was primarily red with the blue completing the upper portion of the mass (Figures 49 & 50).

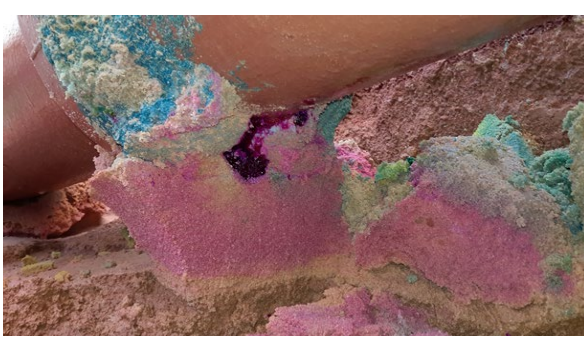


Figure 49: Neat Red Grout Observed Below Pipe

Figure 50: Dissection of Defect C

The yellow grout (third increment) mixed with the blue grout and presented itself as green in many

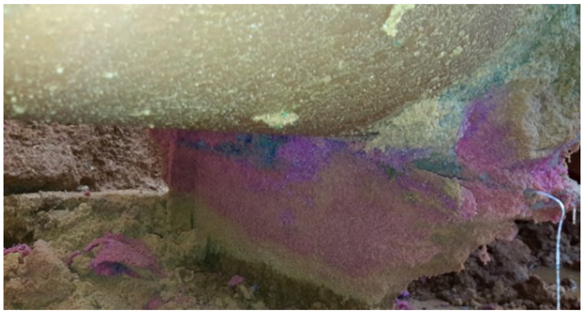


Figure 51: Observation of Grouted Mass Below Pipe

Figure 52: Dissection of Lower Portion

portions of the mass. No yellow grout was observed in the red grout. The third grouting increment formed outside the first two colored masses. The mass around the defect was primarily blue with an absence of red. The longer gel time allowed for the first pumped red grout to migrate below the pipe.

Tests 1 and 2 (Colored Grout) General Observations:
From the two incremental injection grout tests, the following observations were made:

The initial grout that exits the defect always permeates toward the bottom of the pipe embedment zone regardless of gel time.
If using a shorter gel time (20 seconds in sand bedding), the amount of grout that will migrate below the pipe is minimal and will not provide the desired pipe stabilization. Therefore, with longer the gel times, more grout migration and better the pipe support are achieved.

Figure 53: Neat Grout at Center of Defect

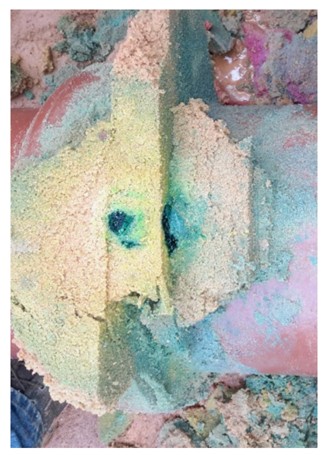


Figure: 54: Top View Neat Grout

A side-by-side comparison of the dissection of the gel/soil matrices revealed the effect of the gel time on the grout movement, the pipe cradle support, and the final seal. The gel mass that was observed with the shorter gel times sealed the defect earlier (with less grout) but did not provide cradle support. The longer gel time allowed for the creation of the pipe cradle support with the initial grout pumped, whereas the second and third grout injections sealed the defect.

Figure 55: Grouted Mass Below Pipe

Figure 56: Side View Grout Mass

20 Second Gel Time 55 Second Gel Time

Figure 57: Side by Side Comparison between 20 seconds and 55 gel times.

Once grout begins to set up within the bedding, any subsequent grouting steps tend to *create an upward directional mass rather than allowing the grout to migrate below the pipe and saturate the bedding*.

Figure 58: Upward Grouted Mass Above Defect

Figure 59: Side View of Grouted Mass

The grout materials used in the colored grout injection tests did not contain any latex or other additives. This was to allow for the observation of the different grout injections using colored dyes. The following tests utilized grout formulas containing 1.5% latex (by total batch volume). The resulting grout matrices which included latex exhibited increased stiffness, compressive strength, and flexibility.

Figure 60: Colored Grout Layers

Figure: 61: Gel/Soil Matrix Removed and Dissected

Sand Bedding Tests 3 & 4

Clean sand is a common Class IV bedding material used to bed, protect, and bury utilities such as water, sewer, and electrical conduit piping. It is sized with no more than 8% fines to ensure proper drainage. Its typical porosity is around 31%.

Figure 62: Pipe with Defects Installed In Sand Bedding

Sand Bedding Goals:
The goal of the Sand Bedding Test was to determine where the grout traveled given two significantly different gel times with similar pumping rates. A 12% acrylamide mixture was used with an additive of 1.5% latex. Since there were no delays between grout injection amounts due to dye color changes, the method used to test, seal, and retest mimicked the standard grouting procedures described in NASSCO's Suggested Standard Specifications for Packer Injection Grouting (2014). Step grouting methods were used until a positive 4 psi or higher air-test result had been achieved. Two tests were conducted using a 55 second gel time and a 23 second gel time.

Following the test cell construction procedures described earlier, the trench was constructed of native North Carolina neat red clay. The pipes were then bedded in clean sand in four-inch lifts and then hand tamped until six inches of sand backfill was placed over the crown of the pipe. Two and a half feet of material was placed on top of the pipe and then plywood plates with sand filled super-sacks were placed on top.

Figure 63: Pipe Installation Prior to Backfill

Test 3:
Using a 55 second gel time, the grouting procedure remained consistent to the prior procedures described, as well as the order in which the defects were sealed – Defect B (full circumferential) first, then Defect C (12 o'clock defect), and finally Defect A (3 o'clock defect). Each defect was confirmed to be sealed via an air test with the minimum amount of 2.5 gallons injected at Defect B, 3.5 gallons injected at Defect C, and 2.75 gallons injected at Defect A.

Test #3 - Sand, 55 sec gel time.

	A Defect - 3 O'clock Position		B Defect - Circumferential		C Defect - 12 O'clock Position
1	Pump Grout - 1.0 gal.	1	Pump Grout - 2.5 gal.	1	Pump Grout - 2.5 gal.
2	Wait 120 seconds.	2	Wait 30 seconds.		Note at 0.5 gal - VP = 8 psi.
3	Pump to 1.5 gal.	3	Test and Pass	2	Wait 60 seconds.
4	Wait 60 seconds.	4	Deflate, Inflate, Retest, Pass	3	Test and Fail
5	Pump to 2 gal	5	Stop Test	4	Pump to 3.5 gal. VP = 7 psi
6	Wait 60 seconds.			6	Wait 60 seconds.
7	Test and Fail.			7	Test and Pass at 9 psi
8	Pump to 2.75 gal.			8	Deflate and retest - Pass at 5, 10, and 12 psi
9	Wait 60 seconds.			9	Stop Test
10	Test and Pass				
11	Stop Test				

Once a seal was achieved, the overburden was removed and each of the grout masses were meticulously exhumed using small hand tools and light water washing.

Figure 64: Removal of Loose Backfill After Grouting

Figure 65: Determining Grouted Mass

Figure 66: Removing Loose Soils Around Mass

Figure 67: Full Extent of Grouted Mass Revealed

Defect C – 55 Second Gel Time

Upon general excavation the grout mass that formed at the defect located at the 12 o'clock position migrated below the pipe providing the cradle support of the invert and surrounded the pipe.

Figure 68: Grout Migration Below Pipe

Figure 69: Top View Grouted Defect

Defect B – 55 Second Gel Time
Upon general excavation it was observed that the grout mass that formed at the circumferential fracture defect migrated below the pipe providing the cradle support of the invert and surrounded the pipe.

Figure 70: Side View Grouted Defect

Figure: 71: Top View Grouted Defect

Defect A – 55 Second Gel Time
After general excavation it was observed that the grout mass formed at the defect located at the 3 o'clock position, migrated below the pipe providing the cradle support of the invert, but did not surround the pipe. However, it did create a seal providing a passing air test.

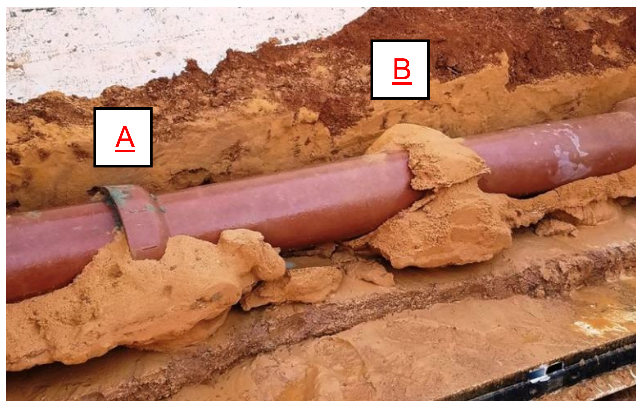


Figure 72: Defects A & B Seals and Pipe Support

Observations
The following observations were noted based on the 55 second gel time within a sand-based backfill:

The first observation was that ***the grout initially descended downward and filled any bedding void under the pipe***. There was no mixing of sand and grout because there was no sand in that void space area. The settlement voids in the outside invert and haunch areas are typical of many

Figure 73: Neat Grout Below Pipe

Figure 74: Neat Grout

Figure 75: Voided Area Below Pipe

in-situ sewer pipe installations, especially those where leakage into the pipe over long periods has led to migration of pipe bedding material.

After the grout filled the void space (pathway of least resistance), it began to saturate the pipe bedding material. During this time, grout continued to move longitudinally, circumferentially, and laterally (but not upward). Longitudinally, the grout almost connected to the next grout mass traveling approximately one and a half feet in both directions along the pipe. Laterally, we observed ***the grout migrated out to the edges of the pipe trench, stopping where it encountered the compacted clay (which served as the surrogate for undisturbed native soils)***.

Figure 76: Top / Plan View of Grouted Defects

Figure 77: Side View of Grouted Defects A, B, & C

After the grout solidified below the pipe, it began to build up around the pipe creating a seal that encased the defect. At Defects B and C, the grout surrounded the entire pipe circumference. At Defect A, the grout extended above the 3 o'clock position.

Figure 78: Close-Up of Lower Portion of Defect Seals and Pipe Stabilization

The grout was able to penetrate the bedding material filling all voids and reaching the impermeable clay sub-base for Defects A, B, and C. This resulted in significant longitudinal pipe cradle support and damming of water in the trench.

Figure 79: Location of Grout Below Structure

When using a 55 second gel time, we achieved a significant volume of gel/soil matrix below Defects A, B, and C, and around Defects B and C.

Figure 80: Grouted Formation at Defect A

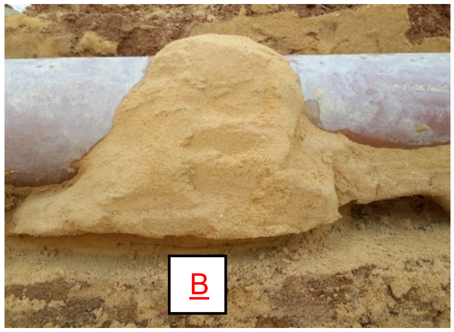


Figure 81: Grouted Formation at Defect B

Figure: 82: Grouted Formation at Defect C

Grout permeation of the soil was observed leading to improved pipe support along the pipe. A thin layer of neat grout was observed between adjacent defects that ran along the bottom of the pipe in the void area.


Figure 83: Bridge Between Formations


Figure 84: Bridge 2


Figure 85: Neat Grout Within Bridge

The defect itself is sealed with neat grout immediately inside and around the defect while filling the potential void space/gaps outside the pipe. The neat grout then permeated the surrounding soil, filled the interparticle void space and created a gel/soil matrix. This provided the additional pipe support and an impervious seal.


Figure 86: Defect Seal


Figure 87: Defect Seal at 12:00 Position

After the loose soil was washed away, this was the gel/soil matrix that remained. The benefits of grouting can be observed in Figure 88:

- *Descending of the grout immediately below the defect*
- *Saturation of the bedding material extending to the trench base*
- *Connecting of the grout masses longitudinally*
- *Creating a seal around the pipe defect (after pipe stabilization mass achieved)*
- *Permeation of the soil beneath the pipes between the defects*
- *Creating a gel/soil matrix supporting the neat grout defect repairs*

Figure 88: 55 Second Gel Time Grouted Soil Formations

Test 4 – Sand Bedding Using 23 Second Gel Time

Test 4 was identical to the previous sand test in construction except a 23 second gel time was used.

Figure 89: Pipe with Defects Installed

Figure: 90: Disassembly of Grouted Test Cell

The 23 second gel time followed the same grouting procedure as before, as well as the order in which the defects were sealed – Defect B (circumferential) first, then Defect C (12 o'clock), and finally Defect A (3 o'clock). Each defect was confirmed to be sealed via an air test with the minimum amount of grout of 2.1 gallons injected at Defect B, 2.8 gallons injected at Defect C, and 2.1 gallons injected at Defect A.

Test #4 - Sand, 23 sec gel time.

A Defect - 3 O'clock Position

1 Pump Grout - 1.5 gal.

Note - Void to 12 psi, stop - VP drops to 8 in 2 seconds.

2 Continue to Pump - at 2-gal, packer shift, VP> 15, blow by at 2.3 gal.

3 Wait 30 seconds.

4 Deflate, Test at 10 psi - Pass

5 Stop Test

B Defect - Circumferential

1 Pump Grout 1 gal.

2 Pump to 2 gal. VP = 8 psi, Stop - VP drops to 0 psi

3 Pump to 2.1-gal VP = 15 psi. Stop - VP stays at 15 psi

4 Deflate, Inflate VP = 10 psi, Test, Pass.

5 Stop Test

C Defect - 12 O'clock Position

1 Pump to 1 gal.

Note - VP = 15 psi. Stop VP drops.

2 Pump to 2.8 gal. Blowby. Pressure holds at 12 psi.

3 Wait 30 seconds.

4 Deflate, Inflate VP = 12 psi. Test, Pass

5 Stop Test

With the 23 second gel time in sand, there was just enough time for the grout to permeate downward and fill the void area underneath the pipe. However, the volume of grout pumped was less compared to the 55 second gel time (Test 3) due to the shorter gel time, and as expected it did not travel as far as it did in the 55 second test. The grout did not mix with the sand under the pipe or with the haunch.

Figure 91: Neat Grout Fills Voids Below Pipe

Figure 92: Neat Grout Continues Along Pipe in Voided Area

In addition to the amount of grout in the void space below the pipe, the shape and size of the resulting gel/soil matrix was significantly different as compared to the 55 second test. Since less grout was pumped, it was expected that the grout structure would be similar but smaller. Fins extending outward provided limited longitudinal pipe support were consistently observed. Smaller "fin-like" grout structures extending outward were observed which provided limited longitudinal pipe support.

Fracture Defect B (full circumference) – Smaller and more localized “fin-like” grout structures with very limited longitudinal spreading were observed when comparing to the 55 second gel test.

Figure 93: Fin formation front view

Figure 94: Side view of grouted defect

Figure 95: Close-up of fin formations

Fracture Defect A (3 o’clock) – Smaller grout structures and reduced longitudinal support was also observed as compared to the 55 second gel test.

Figure 96: Longitudinal Support of Pipe

Figure 97: Sealed Joint with Pipe Support

Figure 98: Grout Matrix observed on opposite side of defect.

Fracture Defect C (12 o’clock) – Smaller grout structures and reduced longitudinal support was observed when compared to the 55 second gel time.

Figure 99: Seal at 12 O’clock Position

Figure: 100: Observed Longitudinal Support of Pipe

Upon dissection of the Defect B fins, it was observed that a significant amount of soil fracking occurred where the grout broke out into neat grout lenses. This was due to the initial pumped grout beginning to gel while continuously pumping fresh grout.

Figure 101: Neat Grout Lens Observed

Observations – Comparing 23 vs 55 Seconds in Sand

Based on Tests 3 and 4, the following commonalities between gel times in a sand-based bedding were observed:

- *Neither the 55 second nor the 23 second gel time grouts penetrated the impermeable native North Carolina Clay trench*.
- *Both grouts filled the void area immediately under the pipe and migrated to the base of the pipe and bedding*.
- *Both gel formulations sealed the defect or joint with neat grout*.

Figure 102: Test Cell Grout Formation Using 23 Second Gel Time

Grout Structure Observations:

1. ***The volume of grout that contacted the sub-base of the trench was much smaller when using a 23 second gel time***. When using a 55 second gel time, the base of the gel/soil matrix was much wider and larger.

Figure: 103: Defect B. 55 Second Gel Time

Figure: 104: Defect B: 23 Second Gel Time

A side-by-side comparison of the results of both tests shows the different formations that were observed between the 23 and 55 second gel time structures. The longer gel time structures were much larger in mass and traveled further underneath the pipe providing better pipe support. Soil saturation of the gelled grout was larger immediately outside of the defect for the longer gel time. The shorter gel time grout formed a small pedestal-like structure immediately under the pipe that was less broad and did not travel as far as the pyramid shape resulting from the longer gel time.

Figure: 115: 55 Second Gel Time Grout Formations

Figure: 106: 23 Second Gel Time Grout Formations

2. ***The shorter gel time resulted in less grout injected. Both formulations were able to seal the defect*.**

55 Second Gel Time		23 Second Gel Time	
Defect	Grout	Defect	Grout
A	2.75 gal	A	2.3 gal
B	2.5 gal	B	2.1 gal
C	3.5 gal	C	2.8 gal

3. ***The shorter gel time resulted in less saturation of the soil and notable fins extending from the grout formation for Defect B***. The formation, while still sealing the defect, provided less pipe support and less gel/soil matrix surrounding the seal, resulting in a less-stable pipe joint.

Figure: 127: Defect B 55 Second Gel Time

Figure: 138: Defect B 23 Second Gel Time

When viewed from above, Defect C (12 o'clock defect) had very similar formations. The amount of the gel/soil matrix was significantly larger on the sides and below the pipe with the longer gel time.

Figure 109: Defect C 55 Second Gel Time

Figure 110: Defect C 23 Second Gel Time

Defect A (3 o'clock position) comparison observations were similar to the Defect C observations. The shorter gel time resulted in a traditional donut shaped structure. With the longer gel time, the grout migrated longitudinally almost connecting to the next grout mass and laterally to the edges of the pipe trench.

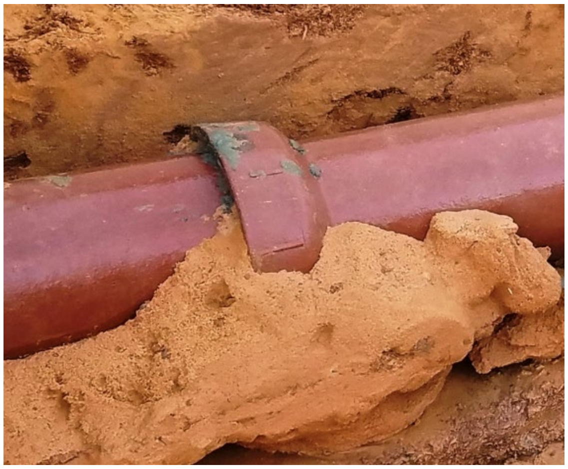


Figure 111: Defect A Seal 55 Second Gel Time

Figure 112: Defect A Seal 23 Second Gel Time

This is the full view of the gel/soil matrices using the 23 second and 55 second gel times after washing with a garden hose for full exposure of the differences in grout shapes and pipe support masses.

Figure 113: 55 Second Gel Time Grout Formations

Figure 114: 23 Second Get Time Grout Formations

Stone Bedding Tests 5 & 6

Test Goals

The goal of the Stone Bedding Test was to determine the difference where the grout traveled when given two different gel times with similar pumping rates. A 12% acrylamide grout mixture was used with 1.5% latex (by total batch volume). Since there were no delays between grout injection amounts due to dye color changes, the method used to test, seal, and retest mimicked the standard grouting procedures as described in NASSCO's Suggested Standard Specifications for Packer Injection Grouting (2014). Step grouting methods were used until a positive air-test result had been achieved. AASHTO #57 stone was used as a bedding material; this stone has a 48% void ratio. Because of the large void space, gel times in clean crushed stone are typically half that in sand as the resistance to liquid migration is much less. The two tests were conducted using a 24 second gel time and a 14 second gel time.

Figure 115: Joint Defect Prior to 57 Stone Installation

Figure 116: Test Cell After Grouting In 57 Stone

Following the test cell construction procedures described earlier, the trench was constructed of native North Carolina neat red clay. The pipes were then bedded in 57 stone in four-inch lifts and then hand tamped until six inches of stone were placed over the crown of the pipe. Two and a half feet of material was placed on top of the pipe and then plywood plates with sand filled super-sacks were placed on top.

Test 5 – 24 Second Gel Time in Stone

Using a 24 second gel time, the grouting procedure remained consistent as the prior procedures described, as well as the order in which the defects were sealed – Joint B (full circumferential) first, then Joint C (12 o'clock defect), and finally Joint A (3 o'clock defect). Defect B was unable to be sealed using the test limit amount of 6.5 gallons of grout. The amount of grout that was used to achieve seals was 4.5 gallons for Joint A, and 6.5 gallons for Joint C. None of the initial grouting sequences passed at 3.5 gallons, Defects A & C required a second injection of grout.

Test #5- Stone, 24 Second Gel Time

A Defect - 3 O'clock Position

1. Pump 2.5 gal. VP = 0 psi
2. Wait 15 seconds
3. Pump to 3.5 gal.
4. Test and Fail
5. Changed to Blue dye
6. Pump. VP = 4 psi at 4.24 gal and then drops.
7. Pump. VP = 15 psi at 4.5 gal then drops to 4 psi
8. Pump to 6.5 gal
9. Wait 60 seconds
10. Test and Pass at 10 psi
11. Stop Test

B Defect - Circumferential

1. Pump 2.5 gal. VP = 0 psi
2. Wait 15 seconds
3. Pump to 3.5 gal.
4. Test and Fail.
5. Change to Blue Dye
6. Pump to 6.5 gal.
7. Test and Fail.
8. Stop Test

C Defect - 12 O'clock Position

1. Pump 1 gal. VP = 0 psi
2. Wait 15 Seconds
3. Pump to 2.0 gal. VP = 0 psi
4. Wait 15 seconds.
5. Pump to 3.0 gal. VP = 0 psi
6. Test. VP = 0 psi
7. Change to Blue Dye
8. Pump - VP spikes and drops at 5.2 gal.
9. Pump - VP spikes and drops at 6.2 gal. Pump to 6.5 gal.
10. Wait 30 seconds. Test and Pass at 12 psi
11. Stop Test

After the completion of the grout injection and dismantling the test cell, Defect A had a bulb of gel/soil matrix surrounding the Defect at the 3 o'clock position, Defect B only had a gel/soil matrix below the pipe, and Defect C (12 o'clock position) had a bulb of gel/soil matrix surrounding the joint but primarily above the pipe. The area below the pipe within the pipe trench was filled with a gel/soil matrix.

Figure 117: Grout Formation After Sealing in Stone

As the bedding was prepared, it was saturated with water. As a result from the large void space and permeability of the stone, a larger amount of free-flowing water was held in the trench. As the grout exited the defects and began to migrate into the bedding, the ground water was trapped within the trench against the test cell walls. This caused dilution of the 12% grout solution where the water was trapped against the metal wall. In a real-world situation, the water would have been pushed by the grout outside of the grouting zone.

Figure 118: Gel / Stone Matrix

Due to the gradation of the #57 stone, the gel/stone matrix consisted of pockets of gelled grout which filled the void spaces between the stone particles. The combination of slower gel time, air testing steps, and high air space in the stone, produced a few small air pockets and water in the gel/stone matrix.

Figure 119: Pockets of Neat Grout

Figure 120: Gel / Stone Matrix Located Under Pipe

Figure 121: Neat Grout Filling Void Below Pipe

Figure 122: Pipe Removed to Reveal Grout Segment Below

Figure 123: Section of Neat Grout Below Pipe

Because an increased amount of grout was pumped, the grout structures created were very large and extremely stiff. The grout matrix was able to withstand several strikes with a shovel.

As observed in other tests, the grout quickly permeated the bedding material below the pipe and then proceeded to fill the void in the haunch areas of the pipe with neat grout.

Due to the low viscosity of the grout, it was able to flow freely through the open voids between the stones. As the grout exited the defect, it filled the voids in between the stones and built upon the base below the pipe. At a gel time of 24 seconds, the uncured grout had enough time to migrate against the sub-base along the length of the pipe improving longitudinal support.

Figure 124: Defect A 23 Second Gel Time in Stone

Figure 125: Defect C 23 Second Gel Time

Test 6 – 14 Second Gel Time in Stone

The grouting procedure remained consistent as prior procedures described, as well as the order in which the defects were sealed – Joint A (3 o'clock defect) first, then Joint C (12 o'clock defect), and finally Joint B (full circumferential). Defect A was sealed using 2.65 gallons of grout, Defect B was sealed using 4.2 gallons of grout, and Defect C was sealed using 2.1 gallons of grout.

Test #6- Stone, 14 Second Gel Time

A Defect - 3 O'clock Position		B Defect - Circumferential		C Defect - 12 O'clock Position	
1	Pump 1.8 gal. VP= 4 psi	1	Pump 2 gal. VP = 0 psi	1	Pump 1 gal. VP = 5 psi
2	Pump to 2.5 gal. VP= 6 psi	2	Wait 30 Sec- Test and Fail	2	Pump to 1.8 gal. VP = 9 psi
3	Stop Pump VP drops to 0 psi	3	Pump. At 2.4-gal, VP = 8 psi	3	Stop at 2 gal, wait 8 secs.
4	Wait 20 seconds.	4	At 4.0-gal VP = 8 psi and drops to 6 psi	4	Pump to 2.1 VP > 15 psi.
5	Test and Pass at 12 psi	5	Test and Fail.	5	Wait 20 seconds
6	At 14 psi, VP drops to 0 psi	6	Pump to 4.2 gal. VP = 12 psi	6	Deflate, Test and Pass at 16 psi
7	Pump to 2.65 gal. VP = 12 psi	7	Wait 15 seconds	7	Stop Test
8	Wait 30 seconds. Test and Pass at 14 psi	8	Test, Pass, Deflate, Retest, and pass at 17 psi		
9	Stop Test	9	Stop Test		
10	Test and Pass at 10 psi				
11	Stop Test				

Once a seal was achieved, the overburden was removed and each of the grout masses was meticulously exhumed. At each of the three defects, grout had migrated below the pipe. Instead of filling up the entire bedding with grout, a smaller base of gel/stone matrix was observed. At Joints A and C, most of the grout formation was located above the pipe, providing no benefit. At Joint B (Circumferential defect), the opposite was observed. A larger base of gel/soil matrix with a smaller grout formation surrounded the defect.

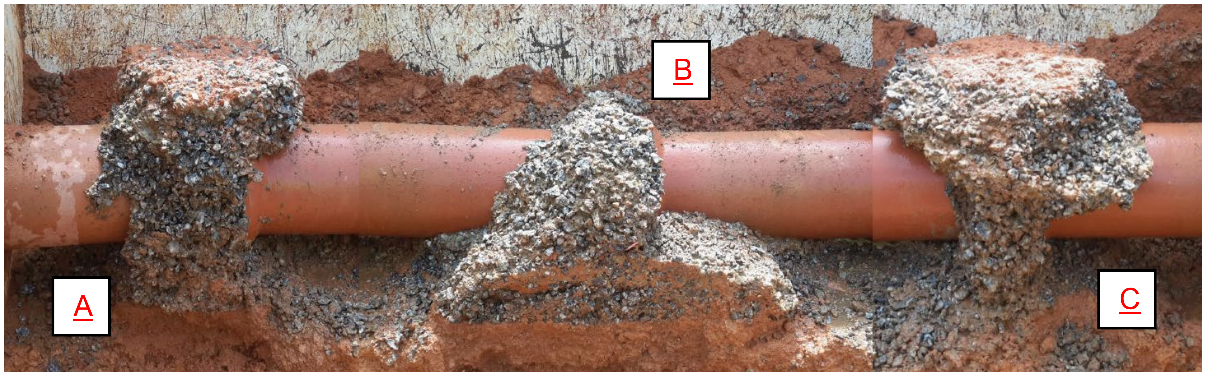


Figure 126: Grout Formations Using 14 Second Gel Time in Stone

Upon further examination of Defect A (3 o'clock position), it was observed that majority of the grout migrated upward after building a thin pedestal below the pipe.

After further dissection of the mass, neat grout was observed to be prevalent closer to the joint.

The 14 second gel time in 57 stone yielded some honeycombing but was less apparent the closer in proximity to the defect.

Figure 127: Grout Filled Circumferential Defect B

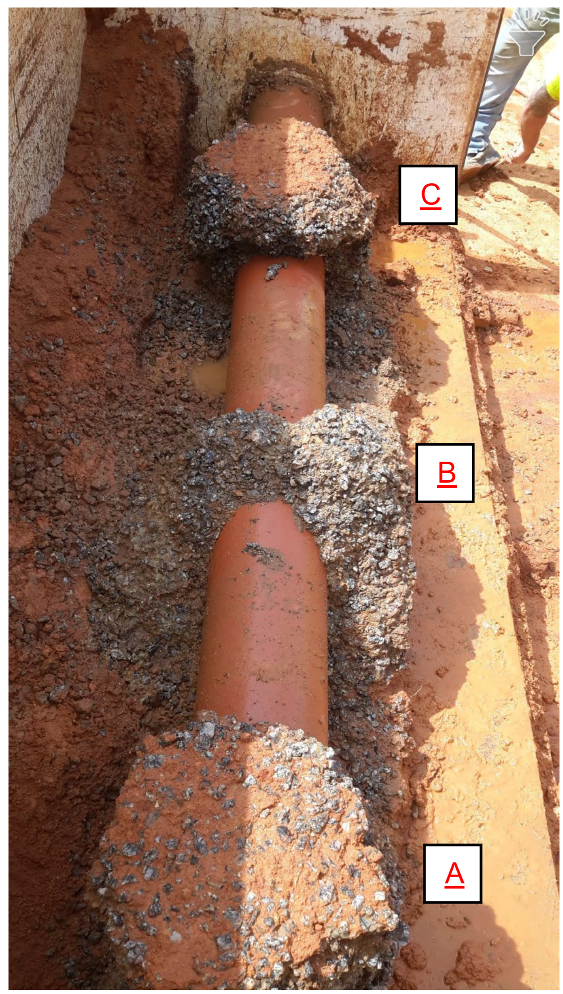


Figure 128: 14 Second Gel Time Grout Formations

It is clear from these tests that grouting in #57 stone requires a much faster gel time than when grouting in sand. It is also clear that too long a gel time results in volumes of grout far in excess of what is needed to stabilize the pipe and form a trench dam (particularly important in clean crushed stone), and that sealing the actual defect is problematic if the gel time is too long. Against that is the tendency of the grout to usually migrate upward if the gel time is too fast. For these tests and matching what has been consistently observed in the field, crushed stone bedded pipe is most effectively sealed with quick gel times (15 seconds). To be conservative, gel times should start long (i.e., risk overgrouting rather than undergrouting or forcing grout upward with too short gel time) and be lowered based on field observations of max grout rules, achievement of grout volume goals, and actual achievement of defect sealing.

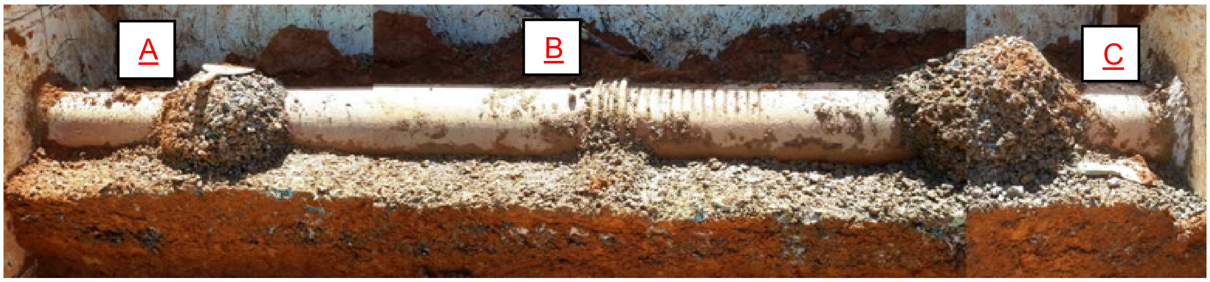


Figure 129: 24 Second Gel Time Grout Formations

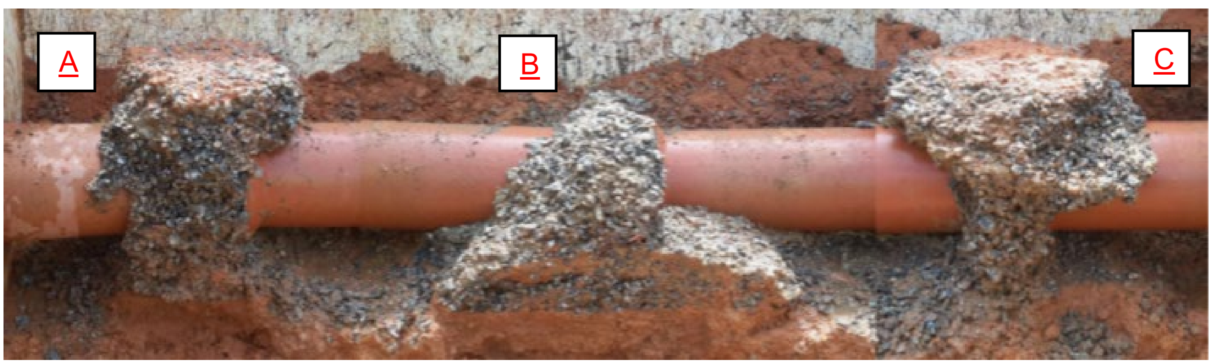


Figure 130: 14 Second Gel Time Grout Formations

Clay Bedding

Tests 7 & 8 – Clay Bedding
Following the test cell construction procedures described earlier, the trench was constructed of native North Carolina neat red clay. The pipes were then bedded in neat red clay in four-inch lifts and then hand tamped until six inches of material was placed over the crown of the pipe. Two and a half feet of clay material was placed on top of the pipe and then plywood plates with sand filled super-sacks were placed on top. A 55 second gel time was used with a pumping rate of three gallons per minute. The defects were constructed of only oakum. No concrete material was used.


Figure 131: Tamping During Install

Test Goals The goal of the Clay Bedding Test was to determine the difference of where the grout traveled when given two significantly different gel times with similar pumping rates. A 12% acrylamide grout mixture was used with an additive of 1.5% latex (by total batch volume). The method used to test, seal, and retest mimicked the standard grouting procedures as described in NASSCO's Suggested Standard Specifications for Packer Injection Grouting (2014).

Test 7 – 55 Second Gel Time, Clay Backfill
Using a 55 second gel time, the grouting procedure remained consistent as the prior procedures described, as well as the order in which the defects were sealed – Joint A (3 o'clock defect) first, then Joint C (12 o'clock defect), and Joint A (full circumferential). Each defect was not able to be sealed with the minimum amount of grout injected into each defect (2.5 gallons). After injection, the wait time before air testing was 60 seconds. After failing the air test, a second injection of grout was performed, and a wait time of 60 seconds was allowed before the second air test. A failure result was received at each of the 3 defects.

Test #7 - Clay, 55 Second Gel Time

A Defect - 3 O'clock Position	B Defect - Circumferential	C Defect - 12 O'clock Position
1 Pump 2.5 gal.	1 Pump 2.5 gal.	1 Pump 1 gal.
2 Wait 60 seconds	2 Wait 30 seconds.	2 Wait 60 seconds.
3 Test and Fail.	3 Test and Fail.	3 Pump to 3.0 gal.
4 Pump to 3.5 gal.	4 Pump to 3.5 gal.	4 Wait 60 seconds.
5 Wait 60 seconds.	5 Wait 60 seconds.	5 Pump to 3.5 gal.
6 Test and Fail.	6 Test and Fail.	6 Wait 60 seconds.
7 Stop Test	7 Stop Test	7 Test and Fail.
		8 Stop Test


Figure 132: Disassembly


Figure 133: Removal of Trench and Backfill


Figure 134: Reveal of Pipe After Grout

After careful exhumation, the grout was found to have fractured the clay by traveling the weakest route and created long fins or filled the fissures within the clay backfill with neat grout. There were no grout rings or masses around the defects. Some fins were up to three feet long and up to 3/8-inches thick. In most cases, the fissures were very thin, but were found to extend far from the point of origin.


Figure 135: Removal of Clay Backfill


Figure 136: Neat Grout Segments


Figure 137: Fins of Grout


Figure 138: Seal at Defect

Test 8 – Clay, 55 Second Gel Time

The second test in clay backfill was repeated using a 55 second gel time and three gallons per minute pumping rate.

The Test Cell was constructed in the same manner as prior tests. However, this time hydraulic cement was utilized on Joints A and C creating the 3 o'clock and 12 o'clock defects, while Joint B remained open to recreate a circumferential fracture.

Test 8 – Clay, 55 Second Gel Time

For the final set of tests, the grouting methods were modified. After pumping two and a half gallons of grout into Defects A and B, the wait time was cut from 60 seconds to 30 seconds. An air test was performed, and another gallon was pumped. After waiting 90 seconds, the defect was air tested and failed at Joint A but passed at Joint B. For Joint C, one gallon was pumped. After waiting 30 seconds, the joint was air tested but did not pass. A second gallon was then pumped. After waiting 30 seconds it did not pass the air test again. Another gallon of grout was pumped, and after waiting 30 seconds another air test was performed and failed. A final half gallon was pumped, and after 90 seconds the defect was air tested, and passed.

Figure 139: Grout Installed in Clay Backfill

Figure 140: Neat Grout Along Bottom of Pipe

Test #8 - Clay, 55 Second Gel Time

A Defect - 3 O'clock Position	B Defect - Circumferential	C Defect - 12 O'clock Position
1 Pump to 2.5 gal.	1 Pump to 2.5 gal.	1 Pump to 1 gal.
2 Wait 30 Seconds.	2 Wait 30 Seconds.	2 Wait 30 seconds. Test and Fail.
3 Test and Fail.	3 Test and Fail.	3 At 40 seconds, pump to 2 gal.
4 At 40 seconds, pump to 3.5 gal.	4 Pump to 3.5 gal.	4 Wait 30 Seconds, Test and Fail
5 Wait 90 Seconds.	5 Wait 90 Seconds.	5 At 40 seconds, pump to 3 gal.
6 Test and Fail.	6 Test and Pass.	6 Wait 30 Seconds, Test and Fail.
7 Stop Test.	7 Stop Test	7 At 40 seconds, pump to 3.5 gal.
		8 Wait 90 Seconds, Test and Pass
		9 Stop Test

After dissection of the Test Cell, it was observed that there were veins and a thin layer of neat grout that ran along the bottom of the pipe. The veins of grout were observed to be originating from the defects.

Figure 141: Fin Origin at Defect

Figure 142: Neat Grout Fin

The fins were constructed of neat grout with very minor mixing with the clay. Following the path of least resistance, the grout traveled in very thin layers outward from the pipe and extended its reach through any fracture within the clay.

Figure 143: Fins of Neat Grout Throughout Structure

Further dissection of the clay structure proved that the grout only followed the path of least resistance through the fractures. It sometimes traveled upwards with very minimal descent of the grout to areas below the pipe, and little to no gel/clay mixture.

Figure 144: Further Observation of Grout Fins

Figure 145: Fin Origin at Defect

Sometimes thick at points, the fins were nearly 100% pure (neat) grout.

Figure 146: Dissection of Grout Fin

Figure 147: Neat Grout

Figure 148: Following Fin to Source

Figure 149: Grout Followed Path of Least Resistance

Figure 150: Exposing Defect and Seal

Figure 151: Measurement of Fin Thickness

After completion of the dissection of the grout (vein), it was observed that the actual seal at the defect was neat grout.

Figure 152: Defect A Seal

Figure 153: Defect B Seal

Figure 154: Defect C Seal

Clay Test Observations:
Both clay test results and observations revealed:

1. *No grout rings or masses were formed.*
2. *Grout did not mix with the clay.*
3. *Seal around the defect was pure or neat grout.*
4. *Grout traveled in fins through any fissure found in the clay pipe bedding.*
5. *Packer grout injection is not a good long-term rehabilitation solution for pipes bedded in silts and clays.*

Figure 155: Segment of Grout Fin

Figure 156: Neat Grout Fin Dissection

Test Cell Conclusions:

Colored Grout Conclusions:

1. ***Grout on top of the pipe does not prevent pipe movement or provide pipe stabilization.***

   The most important locations for the installation of the grout masses are in the haunch, spring line, and invert of the pipe. Material on top of the pipe does not provide pipe support.

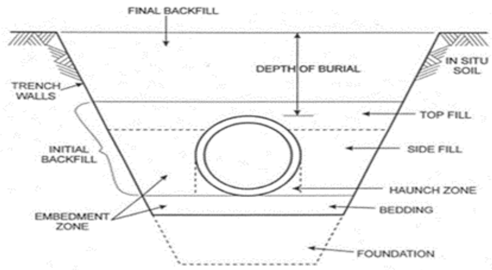


Figure 157: Typical Pipe Installation

2. ***If the first grout pumped is allowed to set, a second injection of grout cascades around the hardened formation.***

   Depending upon the objective of the injection, if stage grouting methods are employed, pumping intervals and gel time must be considered (i.e., bedding support vs. seal only).

Figure 158: Red and Blue Grout Separated

Figure 159: Grout Stages

3. **Grouting using a longer gel time allows for the initial injection of grout to settle below the pipe. The second and sequential injections allows the grout to seal the defect and build reinforcement via a gel / soil matrix surrounding the neat grout seal.**

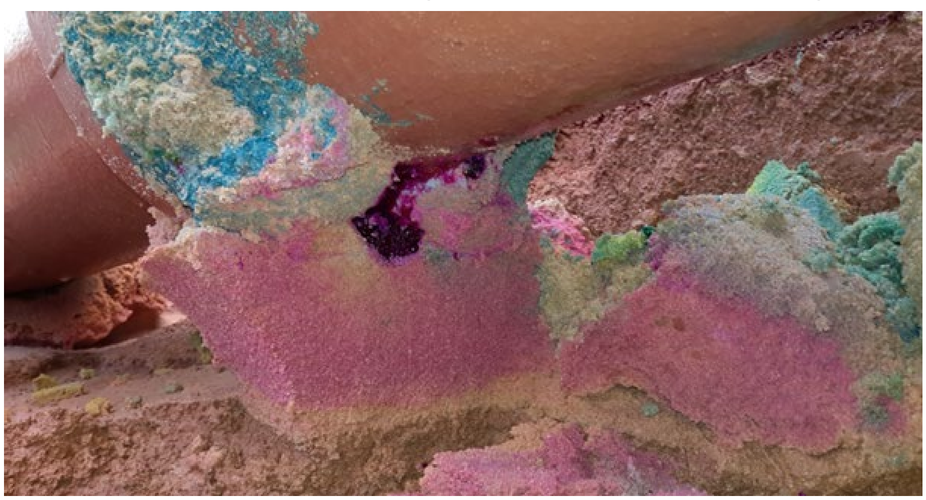


Figure 160: Neat Grout at Void Space Below Pipe

Sand Conclusions:

1. **Longer gel times allows for the grout to fill the void spaces below the pipe, saturate the pipe bedding, stabilize the pipe, and create dams within the pipe trench.**

   The gel/soil matrix was observed to rest on the bedding, then traveled longitudinally and laterally along the pipe and trench.

Figure 161: Colored Grout Layers

Figure 162: Gel / Soil Matrix at Base of Trench

2. **The extent and spread of the pipe support created by the gel/soil matrix was a direct function of gel time (i.e., how long the acrylamide stayed liquid before it began to solidify).**

Figure 163: 55 Second Gel Time Pipe Support

Figure 164: 23 Second Pipe Support Matrix

3. **The testing data confirmed current beliefs that a seal can be achieved with a shorter gel time and less grout, but pipe stabilization that prevents pipe movement is not achieved.**

   During the 25 second gel times (in sand), the void areas below the pipe were filled with neat grout and the defect was sealed but the pipe was not significantly stabilized as compared to the 55 second gel time.

Figure 165: Neat Grout Seal

4. **Although neat grout has limited structural properties, it is a benefit to the pipe bedding when it fills a true void.**

5. **With the longer 55 second gel time, the grout was able to penetrate the bedding material, filling all voids, and reaching the impermeable clay trench (sub-base). This resulted in improved longitudinal pipe support, the actual pipe defect plugged with neat grout, and a strong grout-bedding matrix immediately outside the defect.**

   Visually, the gel/soil matrices at 23 and 55 seconds look notably different in terms of creating pipe support. The 55 second gel time structures were larger in mass and traveled further underneath the pipe. Soil saturation of the gelled grout was larger immediately outside of the defect. The 23 second gel time grout formed a structure immediately

Figure 166: 55 Second Gel Time

Figure 167: 23 Second Gel Time

   underneath the pipe that was less broad and did not travel as far. A shorter gel time also limited the build-up of grout within the trench which is crucial to the prevention of water migration.

6. **Shorter gel times result in less saturation of the surrounding bedding and created fins of grout as opposed to creating a solid mass encapsulating the pipe. Longer gel times yielded a larger gel-soil matrix adjacent to the defect, and improving embedment stabilization, pipe support, and added protection to the seal of neat grout.**

Figure 168: 55 Second Gel Time

Figure 169: 23 Second Gel Time

7. **Shorter gel times tend to fract upward through the gelled masses and create larger formations above the pipe.**

8. ***While it is possible to seal a joint with a short gel time and minimal grout injected, the most effective, long-term seal is achieved using a longer gel time that allows additional grout to be installed under and around the pipe.***

   This is because cradling of the pipe is only achieved through longer gel times, which helps prevent pipe movement, create a reinforcing gel/soil matrix surrounding the initial grout seal, and therefore is the key to a long-term seal.

9. **Based on the sand test trials, it was determined that the new NASSCO Specification for Capital Grouting should recommend longer gel times than previously recommended to allow grout to move under and around instead of upward and above the pipe.**

Stone Conclusions:

1. **In stone bedding, larger volumes of grout are necessary to fill the larger void space between stone than what is present in other bedding materials (i.e. sand). However, there is significantly reduced impediment to grout flow in open graded stone as compared to sand, resulting in the grout often moving far from the defect and providing a much larger cradle than necessary. Therefore, gel times in stone need to account for both the larger void space and the reduced impediment to flow. In open graded stone this means that gel times may be 25-50% less than the time compared to sand to achieve the effective seal and pyramid cradle affect.**

   As observed in other tests, the grout quickly permeated the bedding material below the pipe and then proceeded to fill the void in the haunch areas of the pipe with neat grout.

Figure 170: Gel / Stone Matrix

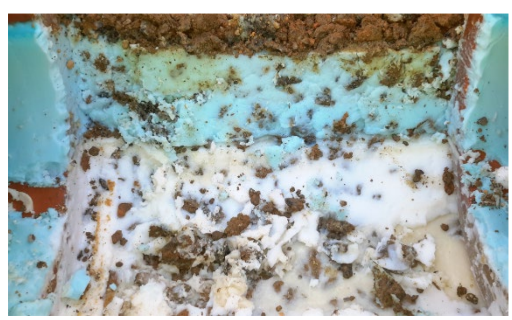


Figure 171: Neat Grout Located Below Pipe

2. ***When grouting in stone, long gel times do not work well.***

   Due to the void space between the stone, a large amount of grout would be required to achieve a proper cradle. A seal can be achieved in clean stone using a short gel time as low as 10-15 seconds. The goal is to achieve the proper amount of grout placement around the defect to prevent infiltration. In some cases, the optimum gel time may be as low as 10-15 seconds to reach a complete seal in stone. The trade-off is there is very little grout provided for pipe stabilization and trench damming.

Figure 172: 24 Second Gel Time Grout / Stone Matrix

3. **A short gel time in open graded stone promotes development of a proper sized cradle beneath the pipe.**

If grouting in pipes solely bedded in stone:

4. **Using a gel time of 14 seconds as compared to 24 seconds and stage grouting allowed for a cradle to be built, avoided honeycombing, and permitted a seal of neat grout immediately outside the defect.**

Figure 173: 14 Second Gel Time Grout / Stone Matrix

   This is very similar to other test results with quicker gel times as the grout immediately descends below the pipe, creating a pedestal. During the second injection, the grout builds upon that thinner base and migrates upward instead of down and around the pipe.

5. **In clean stone bedding, gel times need to be adjusted to be cost-effective in terms of sealing and achieving efficient long-term pipe structural support.**

Figure 174: Defect A at 3 O'clock Position Grouting in Stone

Clay Grouting Conclusions:

When grouting in clay bedding, the following conclusions have been reached:

1. ***Pipes that are supported in clay bedding are not good candidates for Capital Grouting because these materials allow for a very minimal mixture of soil and grout.***
2. ***When sealing pipes embedded in clay, short gel times should be used to limit grout movement through fissures, voids, and gaps.***
3. ***The structure of the clay bedding does not allow for the creation of a ring of grout surrounding the pipe.***
4. ***Cradling of the pipe does not occur as the grout only follows the fissures within the clay bedding structure.***

Figure 175: Grout Fin Extending from Defect

Figure 176: Neat Grout Fin

Overview / General Conclusions:

Grout Placement Conclusions

The Test Cell Study provided visual and physical proof of the movement and characteristics of grout within several different pipe bedding materials. After **eight** tests, the following conclusions were reached regarding grout placement:

1. **Grout always fills the void immediately beneath the pipe with pure or neat grout.**

   After bedding settlement, there is almost always a void located directly underneath the pipe. As grout exits the pipe defect, it descends below the pipe and fills that void with pure grout. This is attributable to the rules of gravity and the path of least resistance, or through the least amount of confining pressure, if it remains liquid.

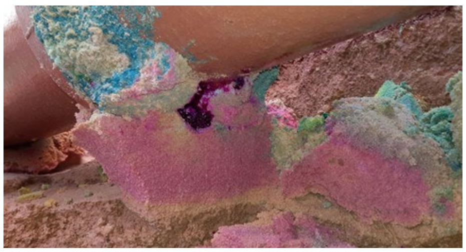


Figure 177: Colored Grout Trial

Figure 178: Sand Grout Trial

Figure 179: Stone Grout Trial

2. **After filling the immediate voids, grout drops to the bottom of the pipe trench while still liquid.**

   The gel time needs to be long enough for the liquid grout to descend through the bedding material and contact the undisturbed trench subbase. The longer the gel time, the wider the base along the pipe profile, and more stabilization is achieved. In no instance did the grout penetrate the tightly compacted native subbase of the Test Cell.

Figure 180: Colored Grout Trial

Figure 181: Sand Trial

Figure 182: Stone Trial

3. **After reaching the pipe trench bottom, grout will cascade around the solidified grout base and create a wide pyramid that is confined to the walls of the pipe trench.**

Grout migration creates a pyramid structure underneath the pipe and increases the cradling and pipe stabilization effect. The grout builds up from the base until it reaches the pipe breach or defect, creating the final seal.

Figure 183: Colored Grout Trial

Figure 184: Sand Trial

Figure 185: Stone Trial

4. **In all cases, the defect itself was sealed with neat grout inside the confines of the defect and the final plug is neat grout.**

   Faster gel times will seal the defect, however- *it will limit how much grout is placed* under the pipe. If you have a fast gel time for an eight-inch pipe, (typically less than 20 seconds) the grout tends to move up and over the top of the pipe, rather than going out and dropping below the pipe.

Figure 186: Defect A Grout Seal (3 O'clock)

Figure 187: Defect C Grout Seal (12 O'clock)

Figure 188: Neat Grout Seal at Defect

Figure 189: Neat Grout Located at Defect

GEL TIME CONCLUSIONS

The following conclusions have been made regarding gel times:

1. **A seal can be achieved using either short or long gel times.**

   As stated earlier, neat or clean grout immediately fills the area surrounding the defect regardless of gel time. This is significant when considering the purpose of grouting. For pre-rehabilitation grouting, shorter times may be desired to temporarily stop infiltration. When using Capital Grouting methods, longer gel times must be utilized.

2. **Shorter gel times promote smaller volumes of grout outside the pipe defect.**

   Fast gel times use 15-35% less grout to achieve a seal. Grouting in sand for both the colored grout tests (1&2) and the latex additive grout tests (3&4) provided consistent results with a longer gel time and 125% more of grout being able to be placed.

3. **Shorter gel times result in grout fin formations at the breakthrough sites.**

   Less grout used at faster gel time means less soil saturation and more gel in fins.

Figure 190: 23 Second Gel Time

Figure 191: 55 Second Gel Time

4. **Longer gel times allow for larger grout masses outside the pipe walls and defects.**

   In pipe bedding materials, the liquid grout will saturate the soils, creating a larger gel/soil matrix outside of the neat grout that is immediately present outside of the defect. The larger mass promotes longevity of the newly installed exterior pipe seal.

5. **Longer gel times promote pyramid formations under the pipe.**

   After the initial grout descends beneath the pipe and reaches the bottom of the trench, a longer gel time will allow the liquid grout to migrate along the trench, creating a larger cradle and promoting pipe stabilization.

6. **Latex adds a significant strength factor to the final grout mass.**

   The resulting grout matrices that included 1.5% latex by total batch volume exhibited increased stiffness, compressive strength, and flexibility.

Figure 192: 23 Second Gel Time Grout Formations

Figure 193: 55 Second Gel Time Grout Formations

References:
standard_installation.pdf (concretepipe.org)
installation-handbook.pdf (ncpi.org)

(1) Clay pipe was chosen due to the ease of handling, access to, transportation, joint length, durability. The replication of the defects is not indicative of new clay pipe installation.
(2) Keefer, Peter, "Underground Waterfalls", (19xx) (pg. 5)
(3) NASSCO, ICGC., "Pipeline Packer Injection Capital Grouting" V.01 (2021) (pg. 6)
(4) NASSCO, ICGC., "Pipeline Packer Injection Pre-Rehabilitation Grouting" V. 2.10 (2021) (pg. 6)
(5) Karol, R. H, "Chemical Grouting" (1990) (pg. 6)