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ESTABLISHING OBJECTIVE TEST PROTOCOLS FOR THE QUANTIFICATION OF WATER-TIGHTNESS OF A REHABILITATED MAIN/LATERAL SEWER CONNECTION

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ABSTRACT: An industry standard for cured-in-place rehabilitation of existing pipes is needed to identify the fundamental engineering practices and objective criteria by which pipe connections shall be evaluated. This paper discusses a proposed protocol for qualification testing of the connection between a main pipe and lateral pipe post-rehabilitation by applying a controlled external hydrostatic pressure and measuring the leak rate. The test addresses both structural properties and water-tight properties of two distinct methods for rehabilitating these pipe joints – the "brim style hat" and the "full-circle" liner systems. These connection seals were tested utilizing a specially-fabricated test tank for applying external hydrostatic pressure to a junction of a main and lateral pipe. The connection seals that were tested include a full circle, one-piece CIPP connection seal using a hydrophilic gasket connection with polyester resin applied to a host pipe junction (as described in ASTM F2561); and a brim-style CIPP connection seal with polyester CIPP resin applied to a junction. The leak rate of each connection seal system was tested under constant ground water pressures based on varying pipe depths; pipe conditions similar to those of a subterranean sewer pipe. This paper reports the findings from the *first phase* in a series of tests. There will be a subsequent second phase where epoxy resin and silicate resins are used for the connection seal. A third and final phase of testing will include the presence of fats, oils and grease (F.O.G.) on the host pipe connection, and the use of high pressure cleaning techniques. The third phase attempts to simulate pipe conditions post-rehabilitation as commonly performed by municipalities during routine cleaning and maintenance. In the present experiment, it was found that the full circle, one-piece CIPP connection seal using a hydrophilic gasket connection applied to a host pipe junction achieved the lowest leak rate, with a 99.99% reduction in leakage observed after 48 hours of installation. The brim-style CIPP connection seal applied to a junction achieved an 85.3% reduction in leakage observed after 48 hours of installation. This report is meant to be a preliminary evaluation of the methods and analysis for testing the seal of the main/lateral connection, and a final comprehensive report will be made available after testing has been completed by an independent third party facility.

1. INTRODUCTION

Specifying Engineers and Collection System Owners are responsible for renewing and maintaining the failing sewer pipes of the nation by either specifying conventional dig and replace methods or trenchless methods. Both methods provide enhanced structural properties, prevent root intrusion and reduce or prevent leaks known as infiltration and exfiltration.

The owner and specifying engineers have a responsibility which requires a significant amount of research and test data to identify the best mode of rehabilitation for the specific type of defect. They must collect product data and analyze these products and processes to validate the technology provider's claims. Scientific testing of water-tightness in cured-in-place main/lateral connection linings focused on external hydrostatic loading has been absent in the municipal rehabilitation market. The owner or the specifying engineer have relied upon information on product characteristics almost exclusively from salesman, advertisements and the technology providers' brochures which are designed to convince potential customers of the alleged quality of a product.

This paper discusses protocol for testing the connection between a main pipe and lateral pipe post-rehabilitation by applying a controlled external hydrostatic pressure and measuring the leak rate. The test includes both structural properties and water-tight properties of two distinct methods for rehabilitating the pipe connections – the "brim style hat" and the "full-circle" liner systems. This report is intended to be a preliminary evaluation of the methods and analysis for testing the seal of the main/lateral connection. A final comprehensive report will be made available after testing has been completed by an independent third party facility to prove reproducibility of the empirical results of this study.

The leak rate of each connection seal system will be tested under constant ground water pressures based on varying pipe depths; pipe conditions similar to those of a subterranean sewer pipe. Other pipe conditions will be simulated in future experiments, including the presence of fats, oils and grease (F.O.G.) and the use of high pressure cleaning post-rehabilitation.

ASTM F1216 has guided the Cured-In-Place Pipelining (CIPP) industry since its initial design criteria was introduced in 1989. There is, however, a neglected yet critical component to the sewer system that must be addressed. The main to lateral connection must be addressed for multiple reasons, not the least of which, are relative difficulty of installation, geometric induced stress concentrations, and un-quantified mechanical degradation caused during re-instatement. This paper will not attempt to solve all the design criteria for Main to Lateral connections, but instead it will attempt to illuminate the considerable need to address these connections by evaluating mathematical modeling and empirical testing of currently available connection sealing methods. With public funds being utilized, an industry standard is required to identify the fundamental engineering practices and objective criteria by which pipe to pipe connections shall be evaluated in order to assist the buyers and balance the claims that are provided through marketing material.

This paper intends to provide a resource in which specifying engineers and owners can assess product claims, especially those which must meet a minimum 50-year service life as described in ASTM F1216. This paper reports the findings from the first phase in a series of tests. There will be a subsequent second phase where epoxy resin and silicate resins are used for the connection seal. The third and final phase of testing will include the presence of fats, oils and grease (F.O.G.) on the host pipe connection, and the use of high pressure cleaning techniques. The third phase attempts to simulate pipe conditions post-rehabilitation as commonly performed by municipalities during routine cleaning and maintenance. This report is meant to be a preliminary evaluation of the methods and analysis for testing the seal of the main/lateral connection, and a final comprehensive report will be made available after testing has been completed by an independent third party facility.

2. BACKGROUND

To begin, it is imperative to establish an economic model for the main to lateral connection. The design considerations addressed in appendix X1 of ASTM F1216 only address the minimum physical characteristics required to prevent the physical failure (buckling) of a CIPP liner. In order to evaluate the CIPP sealing capabilities of the main to lateral connection, or any connection for that matter, it is also required to evaluate the long-term strain or displacement of the connection when subjected to the elements and loads the liner is expected to encounter over the design life specified. This paper will function under all the assumptions put forth in ASTM F1216 to maintain congruence with the failure-prevention design criteria.

Relatively speaking, gravity is a weak but pervasive force. All the design parameters and loads applied to sewer pipe and by extension sewer CIPP are a result of gravity. The most notable of these loads are hydrostatic. As any diver knows, the deeper he travels in the water the more pressure is applied to his body. Therefore, all gravity piping systems should be examined for not only surface level water but also, for the case of low lying areas, water level associated with anticipated flooding.

In keeping with the design assumptions of ASTM F1216, the determination of the hydrostatic forces for sealing must be evaluated at a 50 year design life with a minimum safety factor of 2. In order to compensate for the effects of creep over the 50 year design life, ASTM F1216 recommends the flexural modulus be reduced by 50% unless long-term testing has been performed. Therefore, it is accepted that, due to the viscoelastic nature of CIPP material, creep results in approximately double the displacement seen in the initial testing with standard head rates (i.e. speed at which the flex occurs). Consequently, if the main to lateral connection is to be tested immediately after install it should be tested at 4 times [i.e. 2(safety factor) * 2(long-term displacement factor) = 4] the hydrostatic pressure expected.

An average cost for wastewater treatment is $2.50 per 1,000/gallons. However, even with this relatively low number, the dollars saved by performing infiltration and inflow (hereinafter "I&I") rehabilitation can be significant. The Northcrest-Afton Rehabilitation Project in New Castle County, Delaware described by Shelton and Harmer (2007) was shown to have non-rehabbed *Peak flow rates* of as much as 1,224,000 gallons/day after a rain event. At the average cost rate, treatment of extraneous water from this single basin could cost as much as $3,060.00/day if the peak rate was continuous.

3. DESIGN OF EXPERIMENT

Having established a sound economic base for the reduction of I&I, it becomes necessary to establish a purchasing standard to allow the specifying engineers and owners to define minimum performance specifications required for contractors to bid specific projects. The first step in the creation of these standards is to clearly define the test environment for the rehabilitated main to lateral connection. Assuming the typical connection is buried at approximately 17 feet deep and water is at the surface the hydrostatic pressure is ~7.37psi. Using that baseline and the multiplication factor defined above; the test equipment must be able to produce test pressures of 30psi simulating ~ 70 feet of head. In addition, the testing apparatus must be capable of the following:

1) Testing multiple types of mainline piping/mainline lining;
2) Installation of various sizes of lateral piping (figures 1 and 2);

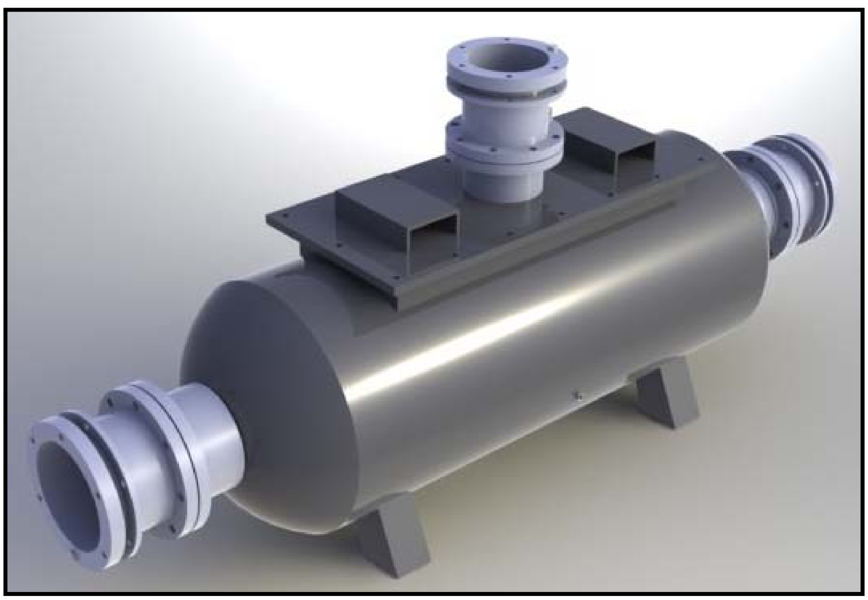

Figure 1: CAD rendering of Hydrostatic Test Tank

3) Capable of allowing for the non-destructive testing of a restrained sample of the lined connection;
4) Capable of regulating the pressure exerted on the connection being tested (figure 3); and
5) Capable of real-time monitoring of pressure (figure 4)
6) Capable of allowing for unobstructed installation of all known rehabilitation techniques.

Taking the baseline, multiplication factor, and the design criteria outlined above into account, the hydrostatic test tank was built.

Figure 2: Hydrostatic Test Tank (as built)

Figure 2: Fill Valve/ Regulator

Figure 4: Pressure gauge and transducer

After completing the design of the pressure vessel the next experimental test parameter to evaluate was the equivalent for the pipe connection in need of rehabilitation. For this analysis, the Northcrest-Afton rehabilitation project was used as a baseline. Assuming the leaks in the non-rehabilitated pipe behave as free jets, as defined in elementary fluid dynamics when subjected to a large reservoir of water, the leak rate is known (refer to equations in [1]) and the average height is known. Therefore, an equivalent "leak-hole" area can be determined (refer to equations 2 and 3).

Non-Peak per connection leak rate at 12ft of head per the Northcrest-Afton Rehabilitation Project (Flow rate was derived from dividing by two the lowest peak rate noted on Fig. 17):

$$Q_{NARP} = 1.8\,{}^{gal}/_{min} = 0.00407\,{}^{ft^3}/_{sec} \qquad [1]$$

$$V = \sqrt{2gh}$$

$$V = \sqrt{2 * \left(32.2\,{}^{ft}/_{sec^2}\right) * (12\,ft)} = 27.8\,{}^{ft}/_{sec}$$

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Equivalent Hole area:

$$A_{eqiv.} = {}^{Q_{NARP}}/_{V} \qquad C_c = {}^{A_j}/_{A_h} \qquad [2]$$

$$A_{eqiv.} = {}^{0.00407\,{}^{ft^3}/_{sec}}/_{27.8\,{}^{ft}/_{sec}} = 0.02108\,in^2$$

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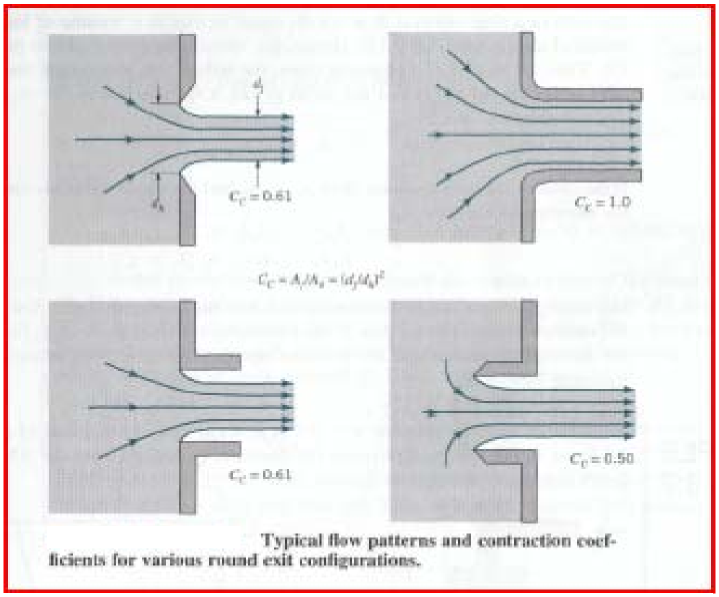

Typical drilled hole C_c= 0.61

Hole Area Equivalent Verification

$$Hole\ Area_{anlg} = \frac{A_j}{C_c} = \frac{0.02105in^2}{0.61} = 0.03450in^2 \qquad [3]$$

$$1/8"\emptyset\ Hole\ Area = \pi * \left({}^{1}/_{16}\right)^2 = 0.01227in^2$$

$$\therefore Hole\ Area_{anlg} \cong 2 * (1/8"\emptyset\ Hole\ Area) + .01in^2\ Mainline\ infiltration\ equiv.$$

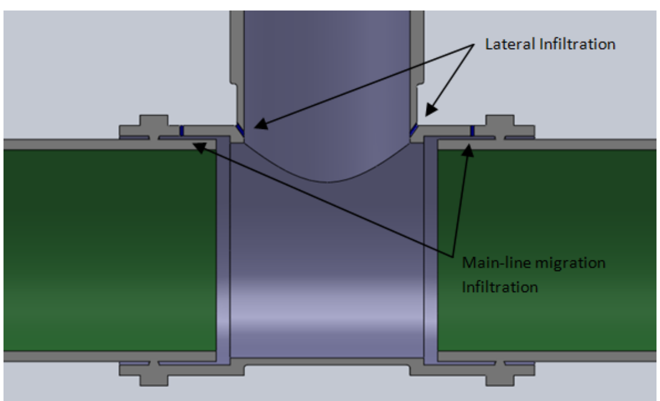

Fig 5: PVC TEE fitting/pipe assembly

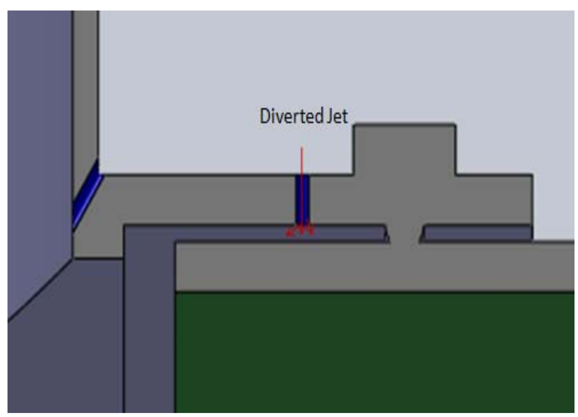

Fig 6: Exploded view of drilled holes

After determining the equivalent "hole" area for an un-rehabilitated connection, testing was performed to verify the actual behavior of equivalent holes compared to their theoretical expected value (Table 1). This testing was comprised of drilling 4 1/8inch diameter holes into a PVC Tee piping assembly. Two holes are directly at the interface connection and simulate lateral infiltration. Two additional holes are drilled through the PVC tee at the crown of the main pipe but do not penetrate the PVC mainline pipe. The second set of holes simulate leaking caused by water tracking behind the mainline liner and have the equivalent free jet area to $0.01in^2$ as described above. See Figures 5 and 6 for hole locations. After drilling the holes, a test was performed to verify the holes' behavior compared to the theoretical calculations above. The hole size or number of holes may be increased, based on the annulus (tightness) between the main host pipe and the mainline CIPP from end to end.

Table 1: Theoretical and Actual Behavior of the Equivalent Holes

	Theoretical	Actual
15 psi	0.00805 ft^3/sec	0.00885 ft^3/sec
30 psi	0.011379 ft^3/sec	0.01028 ft^3/sec

The differences between the theoretical and actual behaviors deviated by approximately 10%. This deviation is most likely due to the pressure "flexing" the PVC Tee and altering the cross-sectional area of the two covered holes. Testing of non-obstructed holes yielded errors of less than 1 percent. However, this tolerance should be noted and therefore pre-lining leak rates should be taken before each test.

4. TEST PROTOCOL

1. Install the appropriate size PVC tee connection and pipe sections into the hydrostatic test tank. In this test, an (8" x 8" x 6") piping assembly extended through the three tank ends.
2. Seal dresser couplings to all three pipe ends.
3. Install a CIPP liner into the PVC mainline pipe from end to end.
4. Robotically reinstate the service connection.
5. Drill two (2) 1/8" diameter holes in the interface portion of the PVC tee connection at a 45° angle at the crown of the main-line portion.
6. Drill two (2) 1/8" diameter holes in the crown of the PVC main host pipe while taking precautions not to penetrate the main-line liner providing an entry point for water to track behind the mainline liner.
7. Install Hydrostatic tank lid and seal.
8. Pressurize the system and note the Pre-lined leak rate (ensure it is within 10% of 17.5 L/min).
9. Install the Main to Lateral connection in accordance with the manufactures instructions.
10. Wait the minimum amount of time per the manufactures instructions for initial cure (e.g. bladder removal).
11. Fill the hydrostatic tank with water and purge air.
12. Slowly increase pressure in the hydrostatic tank at a rate less than 10psi/min to avoid pressure surges on the liner.
13. Pressurize tank to test pressure taking care not to exceed test pressure. Note the maximum pressure exerted.
14. Maintain test pressure for 48 hours (this is a short-term test).
15. Record leak rate at holding pressure and note origins of leaks.

4.A. TEST 1

Subject: *Full Circle, one-piece CIPP Connection Seal using a Hydrophilic Gasket Connection With Polyester Resin (Figure 7)*

Test Details:
- Installed 8" CIPP mainline with polypropylene coating
- Re-instated 6" service lateral
- Installed 8"x6"x3' structural CIPP connection seal in conjunction with a Hydrophilic Gasket
- Full cure achieved using ambient temperature
- Filled tank immediately after cure
- Pressurized tank to 30psi/ ~ 70' hydrostatic head pressure
- Test Results shown in table 4

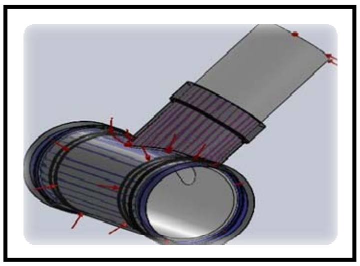

Figure 7: Full-Circle, 1-Piece CIPP Connection Seal

Table 2: Test 1 Test Results:

30psi	Leak Rate	% Reduction
Pre-Lining	17.5 l/min	N/A

Lined + 0hrs	503.5 ml/min	97%
Lined + 48hrs	357.1 ml/min	98%

Test Notes:

- *Initial leakage at 0hrs mostly occurred at the main to lateral interface. The reduction improved over time (e.g. 48-hours).*

4.B. TEST 2

Subject: *Brim Style CIPP Connection Seal (figure 8) with Polyester Resin*

Test Details:

- Installed 8" CIPP mainline with polypropylene coating
- Re-instated 6" service lateral
- Installed 8"x6"x3' felt 6mm thick CIPP Brim
- Full cure achieved using ambient temperatures
- Filled tank with water immediately after cure
- Pressurized tank to 30psi/ ~ 70' hydrostatic head pressure
- Test Results seen in table 3

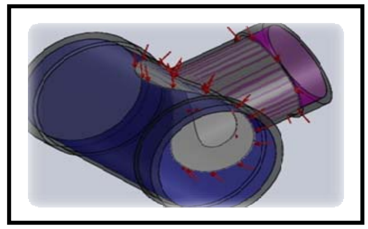

Figure 8: Brim Style CIPP Connection Seal

Table 3: Test 2 Test Results:

30psi	Leak Rate	% Reduction
***Pre*-Lining**	19.7 l/min	*N/A*
Lined + 0hrs	2869 ml/min	*85.4*
Lined + 48hrs	2920 ml/min	*85.3*

Test Notes:

- *Leaks occurred at the brim located at the main to lateral interface.*

5. CONCLUSION

Two different types of connection seals were tested utilizing a specially-fabricated test tank for applying external hydrostatic pressure to a junction of a main and lateral pipe. The connection seals that were tested include a full circle, one-piece CIPP connection seal using polyester CIPP resin including a hydrophilic gasket connection applied to a host pipe junction; and a brim-style hat connection seal with polyester CIPP resin applied to a pipe junction. The leak rate of each of the two connection seal systems were tested under constant ground water pressures of 30 psi. In the present experiment, it was found that the full circle, one-piece CIPP connection seal using a hydrophilic gasket connection with polyester CIPP resin applied to a host pipe junction achieved the lowest leak rate, with a 97% reduction in leakage observed after zero hours of installation and a 98% reduction in leakage observed 48 hours after installation. It is believed that the reduction in leak rate after 48 hours was observed due to the presence of hydrophilic gasket technology. As water infiltrated the connection seal, the water interacted with the hydrophilic gaskets, causing the gaskets to swell. The swelling of the gaskets formed a compression seal between the host pipe and the cured-in-place pipe at the pipe connection. It is possible that the flow rate observed in test # 1 can be reduced even further if the test is repeated and the test time is extended, as the hydrophilic gasket should continue to swell, increasing the compressive sealing force.

The brim-style hat connection seal with polyester CIPP resin applied to a junction having a CIPP main portion included the highest leak rate observed, with an 85.4% reduction in leakage observed after zero hours of installation and an 85.3% reduction in leakage observed after 48 hours of installation. It is noted that an increase in flow rate was measured 48 hours after installation. Since there are no structural reinforcements or gaskets included with the "brim-style hat" assembly, it is believed that the flow rate will continue to increase over time. It is believed that the flow rate will continue to increase over time due to creep, thermal expansion and contraction inherent in plastics. For such a connection seal, it is difficult to ascertain a 50-year service life.

It is evident that further tests need to be performed using pipe conditions encountered in the real world. Additionally, the data tends to show that mainline pipe rehabilitation needs to be considered and addressed in order to provide the most efficient and effective trenchless connection seal. It is imperative that any connection seal technology that is used should provide a 50-plus year design in order to compliment the renewed mainline pipe which has such a design.

The next phases of test will include F.O.G., simulation of cleaning methods as described in the NASSCO cleaning specifications, and liner insertion under active infiltration. Additionally, multiple CIPP resin systems will be tested (e.g. epoxy and silicate). While understanding that these tests report only short-term test results, the final phase of testing will incorporate these same test protocols for determining the long-term effects on a CIPP main/lateral connection liner systems (e.g. 10,000 hour test). We can look forward to an accredited, respected third party to perform the tests, record, report, and corroborate the data disclosed in this paper.

6. REFERENCES

Shelton, J., and Harmer, M. (2007). Multiple Technologies – Maximum Flow Reduction, Proceedings of Mediterranean NO DIG 2007 – XXVth International Conference & Exhibition, Rome, Italy, 10-12 September 2007.