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LONG-TERM FIELD INVESTIGATION OF POLYMER COATED CORRUGATED STEEL PIPE

WRITTEN BY -

Elzly Technology Corporation

Prepared for:

NATIONAL CORRUGATED STEEL PIPE ASSOCIATION

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Introduction

The durability of drainage pipe is a concern to the civil engineer. A recent TRB synthesis discusses drainage pipe durability at length.[1] As a result of continued interest in improving the durability of corrugated steel pipe products, the corrugated steel pipe industry has sponsored extensive research on improved coating materials. As part of this research effort, NCSPA has developed a suggested test protocol for new corrugated steel pipe (CSP) coatings to extend invert life.[2] The NCSPA Test Protocol includes four tiers of test procedures for the evaluation of a new coating. Tiers 1 and 2 are intended to confirm the basic suitability of the coating for use on CSP. Tier 1 includes laboratory performance tests while Tier 2 includes laboratory abrasion tests. Tier 3 is a simulated abrasion test while Tier 4 of the test protocol involves field exposure. A previously published paper reviewed simulated lab testing (Tier 3) and field exposure (Tier 4) data developed for polymer coated CSP.[3] This paper updates the field exposure with observations made after an additional ten years of service.

Background

Polymer coatings were first introduced for CSP applications in the 1970's. These coatings offered a promising means of increasing the corrosion and abrasion resistance of CSP. At the time several different types of polymer coatings were available. Of these polymer coatings, Dow "Trenchcoat" proved to be the best performing and presently is the only polymer coating remaining in production. The product is a tough, rugged heavy gauge protective film with a nominal thickness of 12 mils that is laminated to the inside and outside of galvanized sheet metal prior to forming CSP, providing a corrosion and abrasion barrier on the finished product. The product is fully described in ASTM A742, *Polymer Precoated Sheet for Sewers and Drains*. Numerous laboratory and field studies have been conducted on this product throughout the country. These studies have been conducted by independent engineering firms, DOT's, CSP Fabricators, NCSPA members and the coating supplier.

Appendix 1 contains the data which was collected during the field inspections. The following sections discuss the condition of the pipes at each location and compare the condition to recent inspections.

Analysis and Discussion

The data collected shows that the 51 polymer coated corrugated steel pipes are still performing well after up to 38 years of service in a variety of environments. Figure 1 shows the distribution of the observed coating condition. The majority of the polymer coating was in excellent shape with the remainder exhibiting some or moderate delamination. None of the pipes had significant metal corrosion.

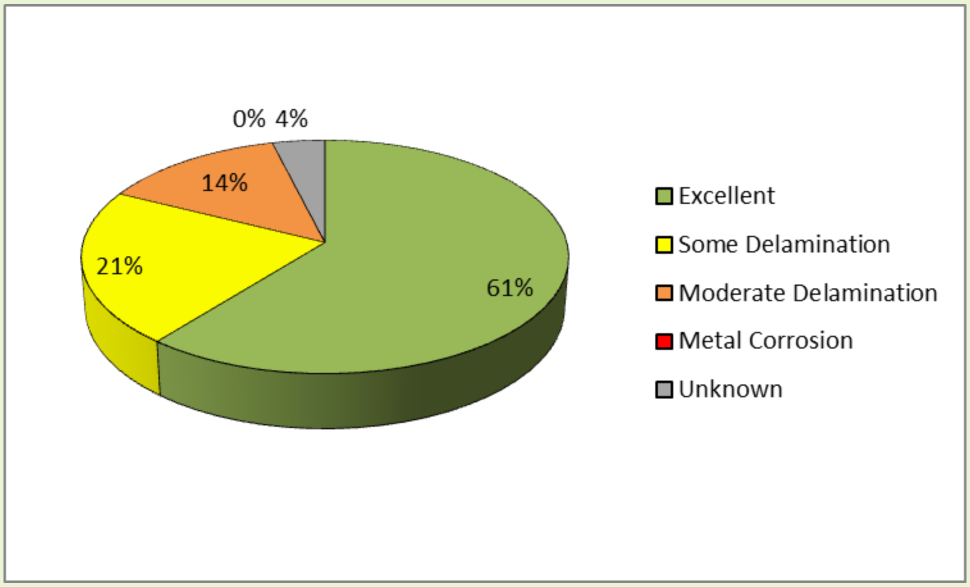


Figure 1. Distribution of polymer coating condition.

To project the service life of the pipes, a model has previously been presented which divides the service life into includes four distinct phases – an initiation period, a polymer degradation phase, a zinc corrosion phase, and a steel corrosion phase. It would be expected that the phases would overlap, but one mechanism would dominate a phase of the pipe life. For simplicity, Figure 2 shows this model graphically. Note that each of the phases on deterioration is correlated to an inspection rating for coating condition (5 through 1).

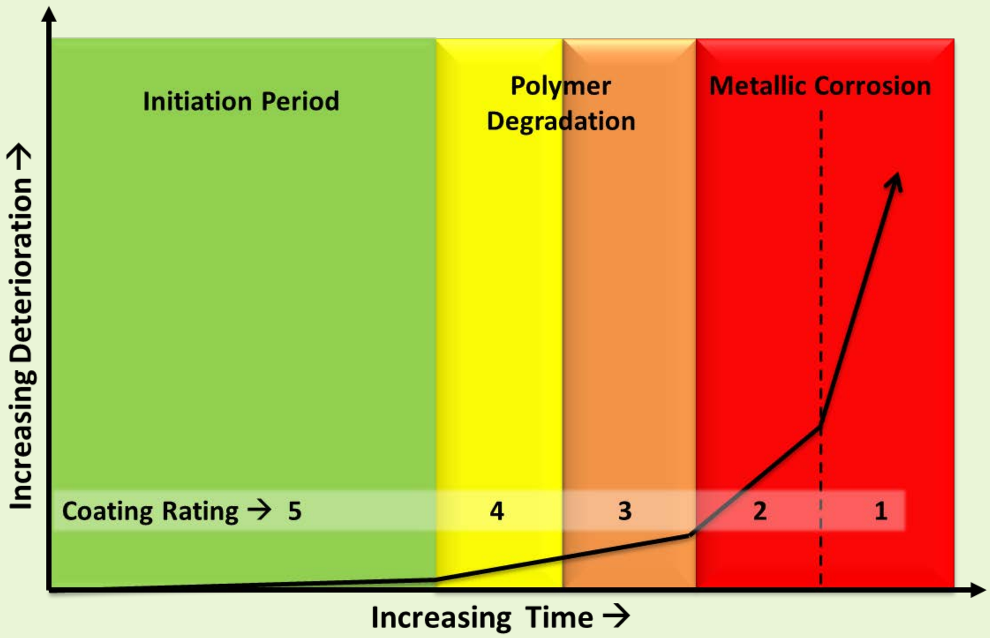


Figure 2. Model of polymer coated corrugated pipe deterioration.

During the initiation period, random events such as mechanical impact can create weak points in the coating. Since the polymer is relatively inert in the service environment, the polymer degradation phase would be dominated by delamination of the polymer coating from the substrate. Even loosely bonded polymer will provide some protection to the galvanized coating both by reducing oxygen access to the surface (and therefore corrosion rate) and by protecting the zinc from abrasive forces. As the polymer is removed, the zinc corrosion will dominate the pipe aging. Finally, steel corrosion will be the dominant failure mechanism for the final years of the pipe life.

As shown in Figure 2, the polymer coating inspection ratings were used to put each pipe into one of the degradation phases in the model. Each installation was further categorized in terms of abrasion level (in accordance with the four FHWA levels of abrasion shown in Table 1) and site corrosivity (in accordance with the three levels shown in Table 2). Site corrosivity was based on the worst case recorded observation of either soil or water conditions in the present or historical inspections. Appendix 2 provides the detailed data used in the analysis.

Table 1 - Abrasion Classification used for Analysis

Level 1, Non-Abrasive – very low velocities and no bedload
Level 2, Low Abrasive – Minor bedloads of sand and gravel with 5 feet per second (fps) maximum flow velocity
Level 3, Moderately Abrasive – Moderate bedloads of sand and gravel with 5-15 fps maximum flow velocity
Level 4, Severely Abrasive – Heavy bedloads of sand, gravel and rock with maximum flow velocity in excess of 15 fps

Table 2 - Environmental Classifications Used for Analysis

Environmental Parameter	Corrosivity Classification		
	Low	***Moderate***	***High***
pH Range	5 to 9	4 to 9	3 to 12
Resistivity	Greater than 1,500 Ω-cm	1,500 to 750 Ω-cm	Less than 750 Ω-cm

Table 3 shows the resulting distribution of the inspected pipes based on corrosivity (low, medium or high), abrasion level (non, low, moderate or severe) and polymer coating condition (3, 4, or 5). For each of the twelve exposure conditions (described by various combinations of corrosivity and abrasion level), the number of pipes, percentage of inspected population and age range is identified for each observed coating condition. For example, of the 23 pipes identified as low corrosion, non-abrasive installations, 70% (16 pipes) were rated a condition 5. After 16 to 38 years, these pipes are still in what the preceding model would describe as an "initiation phase" for polymer coating degradation. The remaining 30% of inspected pipes (7 pipes) were in varying degrees of "polymer degradation" and no pipes were in the "metallic corrosion phase of the model.

Table 3 - Distribution of Inspected Pipes by Abrasion Level, Corrosivity and Polymer Condition

Abrasion Level		Low	Moderate	High
Severe Abrasion	**3**	1 (20%) - 33 yrs		
	4	1 (20%) - 22 yrs	1 (100%) - 23 yrs	
	5	3 (60%) - 33 yrs		
Moderate Abrasion	**3**	2 (50%) - 22 yrs		1 (100%) - 22 yrs
	4	1 (25%) - 22 yrs		
	5	1 (25%) - 35 yrs		
Low Abrasion	**3**			1 (100%) - 22 yrs
	4	1 (14%) - 22 yrs	1 (50%) - 33 yrs	
	5	6 (86%) - 22-38 yrs	1 (50%) - 22 yrs	
Non-Abrasive	**3**	2 (9%) - 18-22 yrs		
	4	5 (22%) - 20-33 yrs		1 (50%) - 28 yrs
	5	16 (70%) - 16-38 yrs	3 (100%) - 18-19 yrs	1 (50%) - 28 yrs
		Corrosivity		

Figure 3 shows the data from Table 3 graphically. Each of the twelve boxes represents a different combination of corrosion and abrasion levels. The circles are sized to represent the number of pipes observed in that environment. The color of the circle indicates the stage of polymer coating life which was observed (based on the polymer coating rating). Note that none of the pipes were observed to be in the metal corrosion phase. In all cases, the polymer coating is still providing protection against metal corrosion even in an environment for which it is not intended (moderate corrosivity and severe abrasion). In the more benign environments, a majority of the polymer coating is still in "excellent" condition.

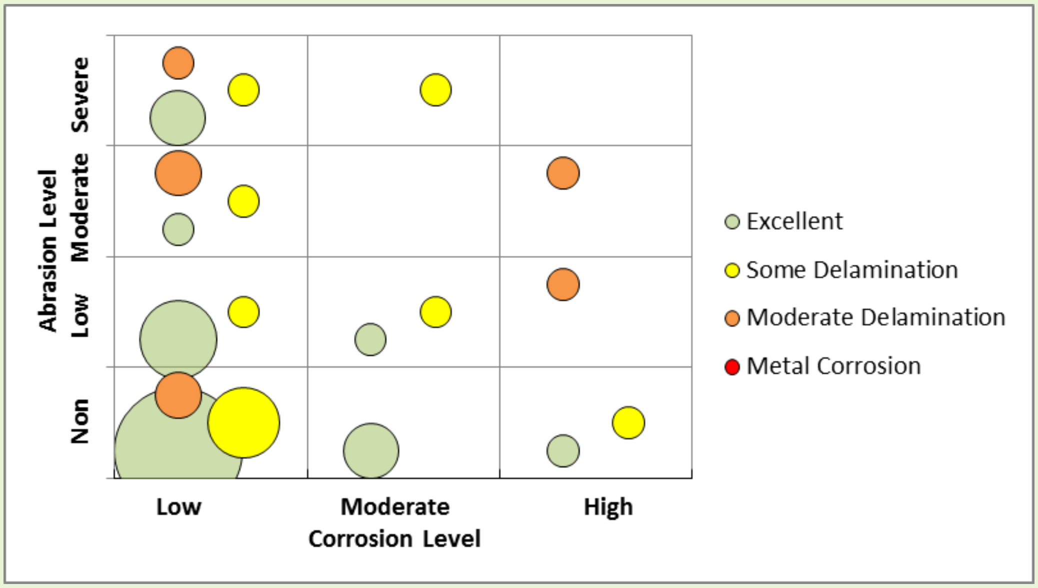


Figure 3. Polymer coating rating by service environment.

To attempt to use the field inspection data to illustrate polymer degradation as a function of age, the data for the 39 pipes which were in the intended service environment (i.e., not severe abrasion or high corrosivity) were grouped into age ranges. The percent of inspected pipes with a given coating condition was calculated. Figure 4 shows the data. For all age brackets except 21-25 years, more than 70% of the polymer coating is in excellent condition. While some minor or moderate delamination has been observed, no significant metal corrosion is being observed for as long as 38 years. In fact, it is estimated that the coating delamination which has been observed so far impacts less than 5% of the coated surface area. This data continues to support the current guidance for an add on life of 80 years for polymer coating on galvanized corrugated steel pipe.

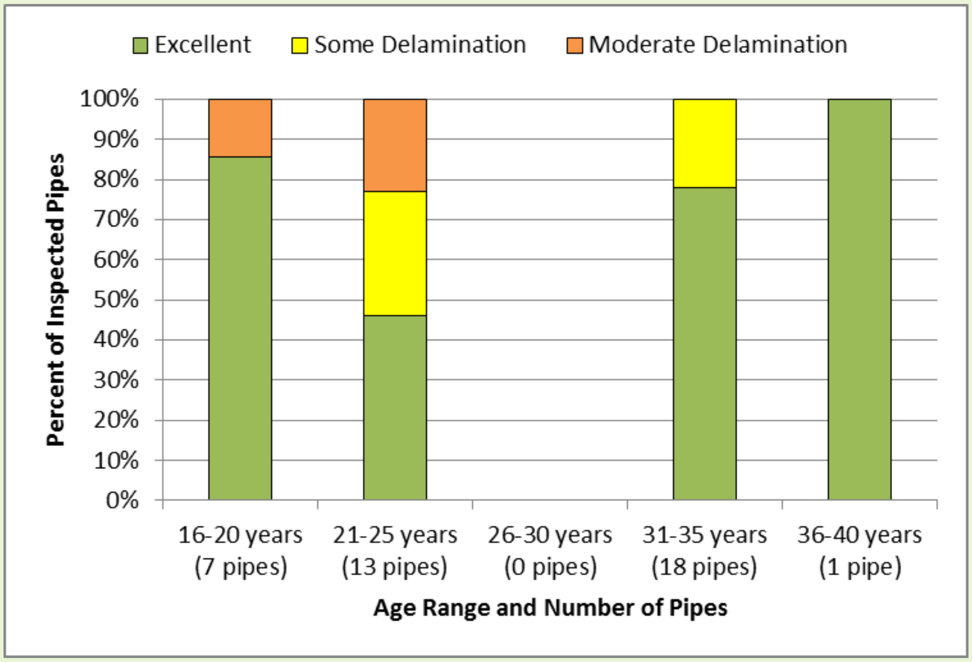


Figure 4. Polymer coating condition as a function of pipe age.

CONCLUSIONS

1. The data continues to support guidance for a polymer coating "add-on" life of 80 years. Polymer coatings were observed to significantly extend the life of corrugated steel pipe.
2. The polymer coating continues to protect the galvanized steel pipe in severe environmental and abrasion conditions beyond the design conditions. This suggests a robust product design approach that is inherently conservative.
3. In all of the pipes, less than 5% of the polymer had coating delamination. This keeps the film intact and protecting the pipe from corrosion. Locations of polymer degradation which were observed are at locations of external damage such as cut edges or handling damage. None of these instances indicated a systemic breakdown of the coating on the entire length of the pipe.

FIELD INSPECTIONS

Most of the present (2011) field inspections were performed by the Chief Engineer of the National Corrugated Steel Pipe Association with the assistance of local DOT and manufacturer representatives. Elzly participated in the first inspection (Sharp County, Arkansas) to ensure that the inspection process was consistent with historical inspections. Elzly performed most of the historical field inspections of the polymer coated CSP installations and was able to provide information on the site locations, help develop the inspection protocol, compiled the inspection results and analyzed the data.

At each pipe location, records were made regarding installation details, coating durability and pipe integrity. Photographs were taken to help document the condition of pipe joints, end treatments, pipe invert and spring line at each installation. Installation details were recorded during each inspection including culvert location (road, mile marker and GPS co-ordinates when possible), pipe diameter, corrugation profile, pipe shape (round, arch, etc) and height of cover.

Observations of the coating condition and environmental conditions at the time of the inspection were recorded. The overall coating condition was observed as well as detailed performance observations at potential weak points in the coating such as lock seams, cut edges, invert and locations where there has been external mechanical damage to the coating. At locations where the coating is abnormally stressed, the extent of coating peeling (also called undercutting) is measured. In the invert, the inspector also looked for indications of coating wear such as roughening of the coating.

When present, water chemistry was determined using Hach test strips for pH, hardness and chloride content. The flow hydraulics where characterized in accordance with the four FHWA abrasion levels based on observations of bedload, water flow, pipe installation and surrounding terrain. Soil chemistry was determined using historical data.

Observations were made regarding the structural integrity of the pipe. This included observations of the joint condition and pipe shape control (ovaling, local buckling).

Arkansas

In June, 2011 seven corrugated steel pipes were evaluated along Grange Road in Sharp County, Arkansas. Each pipe was approximately 32 years old and all but one was found without any water running through them. The one that was found with water had a pH of 7.5 and a hardness of 125. The environmental properties of the water and soil resistivity for each pipe ranged from 3200 to 13500 and 2164 to 4475 ohm-cm, respectively. The pipe coating was in excellent condition with only a few minor flaws ranging from minor nicks and peeling at the exposed ends to some UV degradation at the exposed top.

The pipes were previously inspected in January, 1997.[4] At that time, bedload material and abrasion damage were observed in the inverts. The coating had a roughened look from this abrasion, but the polymer was not breached. The exposed exterior of the pipe had an older, thinner (nominally 3 mils) polymer film which was beginning to delaminate at nicks and gouges. Up to 1/8-inch of delamination was observed. Very light pitting and corrosion of the galvanizing below the polymer on the exterior of the culverts was also observed. All other areas of the Polymer coated CSP's were in new condition.

After more than 30 years after their installation the pipes were in excellent condition and coating seemed to prolonged their service life. Figure 5 shows the typical conditions of the pipe.

Figure 5. Typical conditions of the pipes in Arkansas

Figure 6. Exposed ends of the pipes in Arkansas

WISCONSIN

In August, 2011 seven polymer coated corrugated steel pipes were inspected in the state of Wisconsin. The pipes ranged in age from 28 to 38 years old. The installations included test sites previously inspected and documented by the Wisconsin Department of Transportation. Representatives from the Wisconsin Department of Transportation who visited during the inspection were pleased with the pipe performance. The coating was found to be in-tact, there was negligible rusting and the pipes were structurally sound. Two of the pipes exhibited some polymer delamination at the cut edge of the pipe. One of those pipes also exhibited minor polymer delamination near rivets. The maximum undercutting was found to be 1¾ inches. Minor steel corrosion was noted at the cut ends. Structurally, most of the pipes were in excellent shape. Two of the pipes which were originally installed under a railroad line that is now used as a walking path exhibited some bowing or buckling likely due to construction loads but the coating was unaffected. Figure 7 shows minor buckling at the end of one pipe.

The same pipes were previously inspected in August, 2001.[5] The coating was intact, well adhered and pliable. There was minor damage in the form of scratches in the polymer coating that was likely due to handling damage. Where the galvanized substrate was exposed as a result of this damage, no corrosion was evident. At the cut ends of the pipe, there was typically minor steel corrosion and nominally ¼-inch of coating undercutting. There was no steel corrosion underneath the delaminated film and the zinc coating was intact. The polymer film was tightly adhered at the edges of the delaminated area.

During the ten years that elapsed between inspections, the polymer coated CSP has continued to provide excellent corrosion protection in theses aggressive environments. Figure 8 shows the typical good condition of the polymer. There was no significant progression of steel corrosion from the cut ends. The extent of undercutting was in only isolated areas around the cut ends of the pipe entry and the defects increased from nominally ¼-inch to as much as 1¾ inches.

Figure 7. Long Lake installation WI-1. Note the polymer is in good condition. Buckling near the end appeared to have occurred during installation. No associated coating damage was noted.

Figure 8. Babcock, WI. Typical good condition of Polymer.
The staining on the invert is superficial discoloration from the water line.

NEW YORK STATE

In September, 2011 fourteen polymer coated and asphalt paved corrugated steel pipes in the state of New York were inspected. The pipes ranged in age from 22 to 23 years, diameter from 18 to 48 inches and all were helical types with round shapes. The polymer coating was intact, well adhered and pliable. The pipes were visually ranked from 'good' to 'excellent'. Figure 10 shows a polymer coated pipe in excellent shape. This pipe (and others) had asphalt paving in the invert which was discolored and appears brown in the photograph. Some of the asphalt was missing in all of the pipes as would be expected for 20 year old asphalt paving. Figure 9 shows some of the very minor delamination which was found at the outlet of the pipes in several of the locations. Undercutting was observed either at the invert, the inlet or at the cut edges anywhere from 3/8'' to 1 ¼''.

Four of the pipes appear to have some disjointing of the center section of pipe. The pipes appear to have been installed with galvanized bands which are beginning to fail. There are also small, isolated areas of missing asphalt and polymer at the invert of the center section of each of the pipe with some staining due to deterioration of galvanized band. On each of the four pipes, coating problems only occur in the center section of the three pipe sections.

The same pipes were previously inspected in June, 2001.[6] At that time, the pipes were in very good condition. The polymer coating was intact, well adhered, pliable and appeared like new. The asphalt paving was intact through most of the pipe, but beginning to crack at some of the exposed ends. Where cracking was observed, the asphalt still exhibited good adhesion to the polymer. The polymer under the asphalt was still well adhered to the steel. There was minor damage to some of the polymer that was the result of fabricating and handling. Where the galvanized substrate was exposed, there was no significant steel corrosion. At the cut ends, there was typically some steel corrosion and nominally one-quarter inch of coating undercutting.

Over the past ten years, two of the original pipes were removed. One pipe appears to have been replaced as part of a road modification. It was not clear why the second pipe was replaced. During the ten years since the last inspection, the asphalt paving on the remaining pipes had progressed from cracking to some delamination. This is reasonable performance for the asphalt, especially at the exposed ends. The extent of polymer coating undercutting has progressed from nominally ¼-inch to as much as 1¼ inch. This suggests a maximum undercutting rate of 0.1 inches per year.

Figure 9. Minor delamination at the outlet of the pipe

Figure 10. Typical conditions of coated pipe in New York

Upper Peninsula, Michigan

In September, 2011 polymer coated CSP was inspected at two locations in the Upper Peninsula of Michigan. One installation carries water under Hantz Road in Chippeqa County while the other carries water under Charles Moran Road in Mackinac County. As shown in Figure 11, at each of these locations there are three, 48-inch diameter pipes installed in parallel runs. Each pipe is fabricated from a different material – polymer coasted CSP, aluminum pipe, and standard galvanized pipe. The side-by-side installation of these products allows for comparison of their durability in identical environments. After 33 years of service, all of the pipes remain structurally sound with only a few issues. One of the aluminum pipe has minor buckling but overall is still in good shape. The standard galvanized steel pipe exhibited rusting and metal loss on the bottom half of the pipe and at the outlet of the pipe. The polymer coated CSP had some minor delamination at the corners of most plates as shown in Figure 12. The maximum observed undercutting found on any one of the pipes was 3 inches at one of the cut ends.

The pipes were previously inspected in June, 2000.[7] At that time, the polymer coating was intact, well adhered to the metal, pliable, glossy, and had no signs of blistering. There was minor undercutting (estimated to be up to ½-inch) on most of the edges of the sheets at the waterline and below. There did appear to be consumption of the galvanized coating along some of the edges, but there was not significant metal loss (the corner of the cut edge was still evident). The corrosion did not progress significantly from 2000 to 2011. The polymer was tightly adhered to the edges of the sheets above the waterline. The polymer was tightly adhered around the rivets both above and below the waterline. The polymer was also well adhered around the edge of core samples that had been taken during previous inspections. There were indications of minor abrasion in the invert, but coating loss was not apparent. By comparison, the galvanized pipe had active steel corrosion and metal loss on the lower half of the pipe (though the pipe was still structurally sound).

During the eleven years that elapsed between inspections, the polymer coated CSP has continued to provide excellent corrosion protection in these aggressive environments seen in Figure 13. There was no significant progression of steel corrosion from the cut ends. The extent of undercutting at defects increased from ½-inch to as much as 3 inches, a maximum rate of approximately ¼-inch per year. There were no locations of major coating loss.

Figure 11. Pipes side-by-side under Hantz Rd.

Figure 12. Minor delamination occasionally observed at cut edges. This is expected and has not seemed to be a life-limiting factor.

Figure 13. Typical good conditions of the polymer coating

BERRIEN COUNTY, MICHIGAN

In October, 2011 seven polymer corrugated pipes were inspected in Berrien County, MI. The pipes were installed more than 31 years ago during the construction of the new US-31, north of US-12 in Berrien County, Michigan. Overall the pipes were in excellent condition. Minor delamination was noted in all the pipes at the inverts, inlets and outlets but showed no deterioration to the galvanized steel. The median drains were positioned on a steep slope (estimated to be 30 degrees) which suggests that they intermittently experience high flow and perhaps heavy bedload. One of the median drains contains occasional coating blistering in the invert (approximately every 8 to 10 feet). Figure 14 shows a typical blister after being cut open. Several square inches of the coating could be delaminated when the blister was cut open, but the polymer was tightly adherent at the edges of the blister. The remaining median drains had relatively minor delamination and nicks in the coating from mechanical damage. The defects were small in size (1-inch by 1/16-inch, for example). Approximately ¼-inch of delamination was observed at these defects with no measurable attack on the zinc coating (galvanizing). No steel corrosion was observed except at the cut edges.

The same pipes were previously inspected in July, 2000.[8] At that time eight polymer-coated corrugated steel pipes were inspected at four locations. The polymer coating was in excellent condition, with only minor delamination observed at cut edges and coating defects in the invert.

During the eleven years that elapsed between inspections, the polymer coated CSP has continued to provide excellent corrosion protection in theses aggressive environments. Figure 15 shows the good conditions of the polymer coating that were commonly examined. There was no significant progression of steel corrosion from the cut ends and negligible progression of undercutting at coating defects.

Figure 14. Minor delamination likely due to periodic heavy abrasion and fast flow

Figure 15. Typical good conditions of the polymer coating

Louisiana

In November, 2011 fourteen polymer coated steel pipes were inspected at 7 different locations in Louisiana. The pipes range from 16-28 years old. Eleven out of the fourteen were found to have some sort of standing or flowing water (two of the pipes were full of water and their condition could not be assessed). The pH and hardness of the water found ranged from 6.5 to 8 and 40 to 150, respectively. Aside from some minor buckling and denting, the shape of each pipe was found to be in very good condition. The joints of each pipe were also found to be in excellent condition. Overall the coating of each pipe was found to be in excellent condition. Figure 16 and Figure 17 show the condition of the polymer coating. Polymer coating on the exterior exposed ends of the pipe was subjected to UV degradation and damage from lawn mower impact. Figure 18 shows delamination on the exterior of a pipe which was exposure to UV but did not have any apparent mechanical damage. In no case was there significant corrosion of the exposed metal.

Figure 16. D'Arbbonne Hills, conditions of the polymer found to be great condition

Figure 17. Example of polymer in good condition in Rapides Parish


Figure 18. Delamination observed on the exterior of pipe on Joor Rd. likely due to 20 years of UV exposure

APPENDIX 1 – INSPECTION DATA

This appendix includes information gathered during inspections of polymer coated pipes from June to November in 2011. The pipes were inspected in the states of Arkansas, Wisconsin, New York, Michigan (2 locations) and Louisiana. The results are grouped in this appendix by inspection location. For each location, the data is grouped into three tables and each pipe is assigned a unique identified consisting of a location code and pipe number (e.g., AR-1).

The first table contains basic descriptive characteristics such as age, Height of cover ("HOC" or depth of fill measured in feet), diameter (inches), coating, profile (inch by inch), gage, type (riveted or helical), shape, some sort of specific location (i.e. GPS, mile marker or road name) and other notes.

The second table for each location contains the environmental conditions specific to each pipe. The environmental conditions include water and soil chemistry and resistivity as well as water hardness, observed flow and estimated abrasion level. During the inspection, water was evaluated using Hach pH strips (with a range of 4 to 9) and Hach hardness test kit (ppm of calcium carbonate). Water and soil resistivity (measured in ohm-cm) and soil pH was derived from previous examinations of the pipes completed approximately 10 years ago. Any observed water flow was recorded and the FHWA abrasion level was determined based on observations of bedload, water flow, pipe installation and surrounding terrain.

The third table of each state is the inspectors' comments and rating of each pipes shape, joint and coating condition. The overall structure, joint conditions and coating conditions were graded on a scale of 1 to 5 with the following system:

	Coating Condition	***Joint Condition***	***Shape Condition***
5	Excellent Condition	Overall Excellent condition	Excellent condition
4	Some delamination	Overall good condition, minimal separation less than 1 inch	Overall good condition, some localized deflections or ovaling of pipe
3	Moderate levels of delamination with exposed metal	Separation 1 – 5 inches and/or corrosion of bands beginning	Visible deflections over the length of pipe or directly under roadway
2	Major levels of delamination with exposed metal and corrosion	Severe disjointing greater than 5 inches and/or rusting but not completely corroded through steel, may need remediation in a couple of years	Excessive deflection over the length of pipe, must check %
1	Major levels of delamination with exposed metal corrosion and possible perforation	Severe disjointing, metal bands severely corroded and backfill visible, needs remediation within the next year, potential for failure	Global buckling of pipe, needs replacement, not safe to enter

Arkansas

Descriptive Characteristics

Pipe	*AR-1*	*AR-2*	*AR-3*	*AR-4*	*AR-5*	*AR-6*	*AR-7*
Age	32	32	32	32	32	32	32
HOC, ft.	2	2	2	2	2	3	3
Diameter, in.	60	60	60	48	48	48	48
Coating	Polymer	Polymer	Polymer	Polymer	Polymer	Polymer	Polymer
Profile (in x in)	3 x 1	3 x 1	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2
Gage							
Type	Helical	Helical	Helical	Helical	Helical	Helical	Helical
Shape	Round	Round	Round	Round	Round	Round	Round
GPS Location	36.00332, -91.408329	36.00332, -91.408329	36.00332, -91.408329	36.004404, -91.407334	36.004404, -91.407334	36.005867, -91.40671189	36.005867, -91.40671189
Location Description	Near Calamine	Near Calamine	Near Calamine	Near Calamine	Near Calamine	Near Calamine	Near Calamine
Notes	Grange Rd.	Grange Rd.	Grange Rd.	Grange Rd.	Grange Rd.	Grange Rd.	Grange Rd.

Arkansas

Environmental Observations

Pipe	*AR-1*	*AR-2*	*AR-3*	*AR-4*	*AR-5*	*AR-6*	*AR-7*
pH-Water	7.5	No Water	No Water	No Water	No Water	No Water	No Water
Resistivity-Water (ohm-cm)	3200-13500*	3200-13500*	3200-13500*	3200-13500*	3200-13500*	3200-13500*	3200-13500*
pH-Soil							
Resistivity-Soil (ohm-cm)	2164-4475*	2164-4475*	2164-4475*	2164-4475*	2164-4475*	2164-4475*	2164-4475*
Hardness, ppm $CaCo_3$	125-Hard	N/A	N/A	N/A	N/A	N/A	N/A
Flow	No Flow	N/A	N/A	N/A	N/A	N/A	N/A
Abrasion Level	2	1	1	1	1	1	1

***Data comes from previous study conducted approximately 10 years prior to the present inspections**

Arkansas

Observed Pipe Conditions

Pipe	*AR-1*	*AR-2*	*AR-3*	*AR-4*	*AR-5*	*AR-6*	*AR-7*
Shape	5-Excellent, some denting at ends	5-Excellent, some denting at ends	5-Excellent	5-Excellent	5-Excellent	5-Excellent	5-Excellent
Joint	5-Excellent, ends were not rolled	5-Excellent, ends were not rolled	5-Excellent, ends were not rolled	5-Excellent	5-Excellent	5-Excellent	5-Excellent
Coating	5-Undercutting: 3 mm inside, 10 mm outside, minor cracks	5-Undercutting: 3 mm inside, 10 mm outside, some UV degradation at exposed	5-Minor nicks, peeling at exposed ends, some UV degradation at exposed end	5-Minor nicks, peeling at exposed ends, some UV degradation at exposed end	5-Minor nicks, peeling at exposed ends, some UV degradation at exposed end	5-Minor nicks, peeling at exposed ends, some UV degradation at exposed end	5-Minor nicks, peeling at exposed ends, some UV degradation at exposed end

Arkansas

Additional Photos





Wisconsin

Descriptive Characteristics

Pipe	*WI-1*	*WI-2*	*WI-3*	*WI-4*	*WI-5*	*WI-6*	*WI-7*	*WI-8*
Age	28-38	28-38	28-38	35	38	28-38	28-38	28-38
HOC, ft.	6	6	4	5	3	3	3	6
Diameter, in.	30	30	30	36	30	72	72	96
Coating	Polymer	ALT2	Polymer	Polymer	Polymer	Polymer	Polymer	Polymer
Profile (in x in)	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	5 x 1
Gage								
Type	Riveted	Riveted	Riveted	Riveted	Helical	Helical	Helical	Riveted
Shape	Round	Round	Round	Round	Round	Round	Round	Round
GPS	44.30817264, -90.11127009	44.30817264, -90.11127009	44.213631, -89.614859	44.428608, -87.686938	44.632131, -87.700253	45.852855, -88.665521	45.852855, -88.665521	45.574795, -89.153221
Location Description	Babcock	Babcock	Nekoosa	Strangelville	Luxembourg	Long Lake	Long Lake	Monico
Notes	Rt. 80	Rt. 80	Alpine Rd	Cherneyvill Rd	Town Hall Rd	Rt. 139	Rt. 139	Rt. 8

Wisconsin

Environmental Observations

Pipe	***WI-1***	***WI-2***	***WI-3***	***WI-4***	***WI-5***	***WI-6***	***WI-7***	***WI-8***
pH-Water	7.41	7.41	6.9	9	6.75	7.5	7.5	6
Resistivity-Water (ohm-cm)	1612*	1612*	2273*	1667*	2941*	4000*	4000*	
pH-Soil	7	7	6.9		7	8.1	8.1	
Resistivity-Soil (ohm-cm)	8929*	8929*	3774*	5155*	1704*	23256*	23256*	
Hardness, ppm $CaCo_3$	120-Hard	N/A	N/A	350-Very Hard	N/A	120-Hard	120-Hard	100-Hard
Flow	6" of standing water	N/A	N/A	4' of fast flow	N/A	18" of slow flow	1' @ inlet, and 3' outlet	6" of flow
Abrasion Level	1	1	1	3	1	2	2	2

***Data comes from previous study conducted approximately 10 years prior to the present inspections**

Wisconsin

Observed Pipe Conditions

Pipe	*WI-1*	*WI-2*	*WI-3*	*WI-4*	*WI-5*	*WI-6*	*WI-7*	*WI-8*
Shape	5-Excellent	5	5-Excellent	5-Excellent	5	4-Slight bow in the middle	3-Timber bracing under roadway	4-Some local buckling at top under roadway
Joint	4-Rivets are in good shape	4	4	5	5	4	3-Lockseam separated by max 3’’	4
Coating	4-Some delamination at edge of rivets and sheets, 1 3/4" max	4	5-Some delamination at edge	5	5	5-Max delamination: 10mm x 10mm	5	5

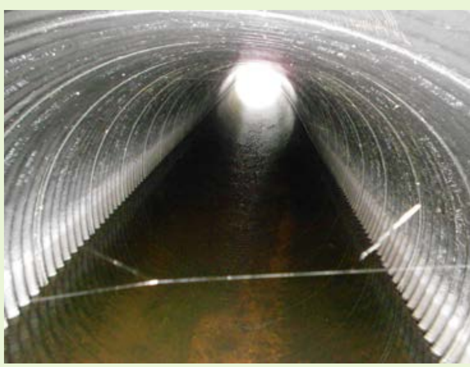
Wisconsin

Additional Photos

















New York

Descriptive Characteristics

Pipe	*NY-1*	*NY -2*	*NY -3*	*NY -4*	*NY -5*	*NY -6*	*NY-7*	*NY-8*	*NY-9*	*NY-10*	*NY-11*	*NY-12*	*NY-13*	*NY-14*
Age	23	23	22	22	22	22	22	22	22	22	22	22	22	22
HOC, ft.	3	8	6	8	5	6	10	2	5	5	12	1	3	1
Diameter, in.	117 x 48	48	48	24	24	24	24	30	30	30	30	36	24	18
Coating	Polymer w/ AP	Polymer w/ AP	Polymer w/ AP	Polymer w/ AP	Polymer	Polymer	Polymer	Polymer w/ AP	Polymer	Polymer w/ AP	Polymer	Polymer	Polymer	Polymer
Profile (in x in)	3 x 1	3 x 1	3 x 1	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2
Gage														
Type	Helical	Helical	Helical	Helical	Helical	Helical	Helical	Helical	Helical	Helical	Helical	Helical	Helical	Helical
Shape	Round	Round	Round	Round	Round	Round	Round	Round	Round	Round	Round	Round	Round	Round
Notes(mile marker)	1072	3063	1286	1285	1291	1297	1310	1314	1714	1714	1715	1710	1704	1698

***Data comes from previous study conducted approximately 10 years prior to the present inspections**

New York

Environmental Observations

Pipe	*NY-1*	*NY -2*	*NY -3*	*NY -4*	*NY -5*	*NY -6*	*NY -7*	*NY-8*	*NY-9*	*NY-10*	*NY-11*	*NY-12*	*NY-13*	*NY-14*
pH-Water	6.79	7.54	6.72	6.32	6.43	6.33	7.48		7.46	7.46	6.5	4.93	6.43	
Resistivity-Water (ohm-cm)	5291*	1020*	3125*	455*	23810*	5000*	357*		3846*	3846*	12500*	26314*	6623*	
pH-Soil	7.4	7.9	5.6	6.2	6.2	6.3	5.9	6.6	7.2	7.2		6.8	7.9	
Resistivity-Soil (ohm-cm)	11494*	5814*	9259*	20408*	13333*	15873*	25000*	25641*	1310*	4310*		5376*	4386*	
Hardness, ppm $CaCo_3$	110	200	40	30	25		40	40	80	80	40	70	80	
Flow	None	18", very fast	6", very fast	6" @ inlet, 12" outlet,	4", very fast	None	2" @ inlet, 8" outlet	3" @ inlet, 6" outlet, fast flowing	3" flowing slowly	6" flowing slowly	4' of fast flow	3-4", very fast flow	not much more than a trickle	None
Abrasion Level	1	4	3	3	3	1	2	2	2	2	3	4	1	1

New York

Observed Pipe Conditions

Pipe	NY-1	NY -2	NY -3	NY -4	NY -5	NY -6	NY -7	NY-8	NY-9	NY-10	NY-11	NY-12	NY-13	NY-14
Structure	5-Excellent	3-Okay, no buckling or ovaling	4-Good except for local buckle at inlet	5-Excellent	4-Good except for local buckle at inlet	5-Excellent	5-Excellent	5-Good in visible sections	5-Good	5-Excellent	5-Excellent	5-Excellent	5-Good	5-Good
Joint	4-Four Joints, some rusting, minimal undercutting 1/4 inch max	2-Three joints. first 2 sections are good. They do have some deterioration of the band. A drop of approx 5" in section 3. Significant separation and misalignment of joint 3 combining sections 3 and 4.	2-Galvanized bands, severe deterioration at band inverts	4-Two joints, both appear to be in good condition despite coating problems in center section	2-Appears to be some disjointing of the center section of pipe	4-Two joints, both appear to be in good condition despite coating problems in center section	3-Appears to be some disjointing of the center section of pipe	4-Unable to tell due to size of pipe	NA-Joins a concrete box culvert	5-Two joints, excellent condition	NA-connects to a concrete basin	NA-connects to a concrete basin	4-Unable to tell due to size of pipe	
Coating	5-Excellent condition, minor blemishes in upper quadrant	4-Unable to see condition of invert, some pealing and undercutting at the cut edges of the pipe at the joints.	3-One location of a large piece peeling off at the 3rd joint.	3-Appears to be missing polymer or asphalt at the invert of center pipe section (2 of 3) with some corrosion of the galvanizing	3-Appears to be missing polymer or asphalt at the invert of center section (2 of 3) with some staining due to deterioration of galvanized band	3-Appears to be missing polymer or asphalt at the invert of center pipe section (2 of 3) with some corrosion of the galvanizing	3-Appears to be missing polymer or asphalt at the invert of center section (2 of 3) with some staining due to deterioration of galvanized band	4-One inch of undercutting @ invert and some asphalt cracking	5-Excellent shape	5-Minimal cracking in asphalt coating, polymer in excellent shape	4-Excellent, some delamination at cut edges with 3/8" undercutting	4-Some asphalt missing, with some delamination and undercutting of 3/4" max	4-Two inch peel back of coating at inlet with some cracking of asphalt coating	4-One and a 1/4 '' peel back at invert, some cracking of asphalt coating

New York

Additional Photos










Upper Peninsula, Michigan

Descriptive Characteristics

Pipe	***MIU-1***	***MIU-2***	***MIU-3***	***MIU-4***	***MIU-5***	***MIU-6***
Age	33	33	33	33	33	33
HOC, ft.	2	2	2	6	6	6
Diameter, in.	48	48	48	48	48	48
Coating	Polymer	Galvanized	ALT2	Polymer	Galvanized	Aluminum
Profile (in x in)	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2
Gage	12	12	12	12	12	12
Type	Riveted	Riveted	Riveted	Riveted	Riveted	Riveted
Shape	Round	Round	Round	Round	Round	Round
GPS	45.99857162, -84.78284319	45.99857162, -84.78284319	45.99857162, -84.78284319	46.18249547, -84.55092093	46.18249547, -84.55092093	46.18249547, -84.55092093
Notes	Bob Moran Rd.	Bob Moran Rd.	Bob Moran Rd.	S. Hantz Rd	S. Hantz Rd	S. Hantz Rd

Upper Peninsula, Michigan

Environmental Observations

Pipe	***MIU-1***	***MIU-2***	***MIU-3***	***MIU-4***	***MIU-5***	***MIU-6***
pH-Water	7	7	7	7	No Water	No Water
Resistivity-Water (ohm-cm)	8226*	8226*	8226*	1022*	1022*	1022*
pH-Soil						
Resistivity-Soil (ohm-cm)	2164*	2164*	2164*	4475*	4475*	4475*
Hardness, ppm $CaCo_3$	200-Hard	200-Hard	200-Hard	200-hard	N/A	N/A
Flow	3" of slow flow	3" of slow flow	3" of slow flow	12" of standing water	N/A	N/A
Abrasion Level	2	2	2	2	1	1

***Data comes from previous study conducted approximately 10 years prior to the present inspections**

Upper Peninsula, Michigan

Observed Pipe Conditions

Pipe	*MIU-1*	*MIU-2*	*MIU-3*	*MIU-4*	*MIU-5*	*MIU-6*
Structure	5-Excellent	5	5	5	5	5
Joint	5-Two joints, excellent condition	4	4	5	4	4
Coating	5-One delamination spot 1"x6"	2	4	4-Some delamination at the corner of most of the plates max of 3" undercutting	3	4

Upper Peninsula, Michigan

Additional Photos






Berrien County, Michigan

Descriptive Characteristics

Pipe	*MIB -1*	*MIB -2*	*MIB -3*	*MIB -4*	*MIB -5*	*MIB -6*	*MIB-7*
Age	33	33	33	33	33	33	33
HOC, ft.							
Diameter, in.	24	30	36	30	30	18	30
Coating	Polymer	Polymer	Blacklad	Blacklad	Blacklad	Blacklad	Polymer
Profile (in x in)	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2
Gage	12	12	12	12	12	12	12
Type	Helical	Helical	Helical	Helical	Helical	Helical	Helical
Shape	Round	Round	Round	Round	Round	Round	Round
Other	Side Drain	Cross Drain	Median Drain	Cross Drain	Median Drain	Median Drain	Median Drain
Notes	Rt. 31	Rt. 31	Rt. 31	Rt. 31	Rt. 31	Rt. 31	Rt. 31

Berrien County, Michigan

Environmental Observations

Pipe	***MIB -1***	***MIB -2***	***MIB -3***	***MIB -4***	***MIB -5***	***MIB -6***	***MIB-7***
pH-Water	No Water	No Water	No Water	7	7	No Water	No Water
Resistivity-Soil (ohm-cm)							
pH-Soil							
Resistivity- Water (ohm-cm)							
Hardness, ppm $CaCo_3$	N/A	N/A	N/A	120-Hard	120-Hard	N/A	N/A
Flow	N/A	N/A	N/A	Standing water at inlet	4 '' of slow flow	N/A	N/A
Abrasion Level	1	1	1	1	2	1	1

Berrien County, Michigan

Observed Pipe Conditions

Pipe	*MIB -1*	*MIB -2*	*MIB -3*	*MIB -4*	*MIB -5*	*MIB -6*	*MIB-7*
Structure	5-Excellent	5-Excellent	5	5	5	5	5
Joint	couldn't determine	5- In great shape	5	4-Field welds at outlet were exposed			
Coating	4-Some delamination at entrance, 2 1/2 max exposed, no deterioration of galvanizing	5	3-Some blistering and delamination along the invert approx. every 8 - 10 feet	4-Delamination at invert of inlet, delamination at second joint	5-Some delamination at the invert of the inlet	5-Some delamination at invert inlet approx 6 x 12 inch	5-Some nicking at the edges

Berrien County, Michigan

Additional Photos

Louisiana

Descriptive Characteristics

Pipe	*LA-1*	*LA -2*	*LA -3*	*LA -4*	*LA -5*	*LA -6*	*LA -7*	*LA -8*	*LA -9*	*LA -10*	*LA -11*	*LA -12*	*LA -13*	*LA -14*
Age	28	28	16	16	16	18	19	19	18	21	21	21	23	23
HOC, ft.	15	7	3	3	3	2	4	5	3	4	4	4	18	18
Diameter, in.	21	24	90	90	90	30	48	48	45	84	84	84	90	90
Coating	Polymer	Polymer	Polymer	Polymer	Polymer	Blacklad	Polymer	Blacklad	Polymer	Blacklad	Blacklad	Blacklad		
Profile (in x in)	2 2/3 x 1/2	2 2/3 x 1/2	5 x 1	5 x 1	5 x 1	2 2/3 x 1/2	2 2/3 x 1/2	2 2/3 x 1/2	Spiral Rib	3 x 1	3 x 1	3 x 1	3 x 1	3 x 1
Gage	12	12												
Type	Helical	Helical	Helical	Helical	Helical	Helical	Helical	Helical	Spiral Rib	Helical	Helical	Helical	Helical	Helical
Shape	Round	Round	Round	Round	Round	Round	Round	Round	Round	Arch	Arch	Arch	Round	Round
Notes	Napoleonville	Napoleonville	Terrebonne	Terrebonne	Terrebonne	Baton Rouge	Rapides Parish	Rapides Parish	D'Arbonne Hills	Kentwood	Kentwood	Kentwood	Grosse Tete Bayou	Grosse Tete Bayou

Louisiana

Environmental Observations

Pipe	*LA-1*	*LA -2*	*LA -3*	*LA -4*	*LA -5*	*LA -6*	*LA -7*	*LA -8*	*LA -9*	*LA -10*	*LA -11*	*LA -12*	*LA -13*	*LA -14*
pH-Water	7.5	7.25	6.75	6.75	6.75	6.5	7.8	7.8	8.51	7.4	7.4	7.4	5.84	5.84
Resistivity-Water (ohn-cm)	2900*	4700*	3400*	3400*	3400*		6600*	6600*	1600*	18000*	18000*	18000*	1100*	1100*
pH-Soil	8.05	8.05					8.45	8.45	8.15				6.83	6.83
Resitivity-Soil (ohm-cm)	700*	700*					1200*	1200*	1200*				800*	800*
Hardness, ppm $CaCo_3$	150-Hard	N/A	120-Hard	120-Hard	120-Hard	125-Hard	125-Hard	125-Hard	125-Hard	40-Soft	40-Soft	40-Soft		
Flow	Trickle flow	N/A	3/4 full	3/4 full	3/4 full	Trickle flow		approx 3 inch of standing water	some standing water	mostly sediment	6 inches of flow	mostly sediment	Filled to the top	Filled to the top
Abrasion Level	1	1	1	1	1	1	1	1	1	1	1	1	1	1

***Data comes from previous study conducted approximately 10 years prior to the present inspections**

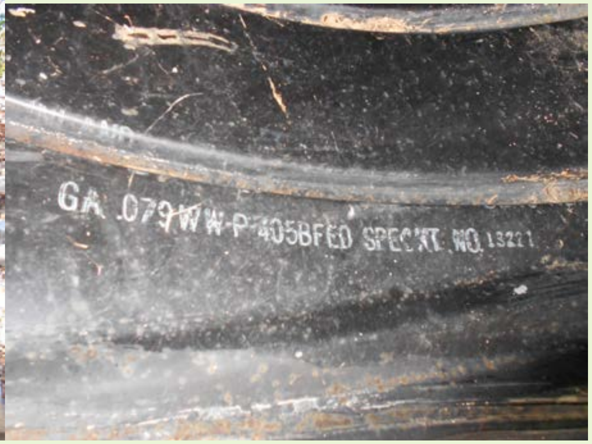
Louisiana

Observed Pipe Conditions

Pipe	LA-1	LA -2	LA -3	LA -4	LA -5	LA -6	LA -7	LA -8	LA -9	LA -10	LA -11	LA -12	LA -13	LA -14
Structural	5	5	5	5	5	5	5	5-Some denting around outlet due to mowers	5-Some local buckling at top near basin entrance underneath grate cover, may have been due to construction	5	5	5		
Joint	5	5-Only checked with light	5- Only one	5	5	5	Attaches to concrete catch basin		No joints	5	5	5		
Coating	5-Some uv degradation at ends, no undercutting	4-Some delamination at inlet but no undercutting	5-Some uv degradation on the exterior of lock seams	5-Some uv degradation on the exterior of lock seams	5-Some uv degradation on the exterior of lock seams	3-Delamination at exterior top of outlet with significant undercutting, no metal corrosion, nicked up by mowers	5-Some abrading at exterior lock seams	5-Some delamination on exterior of exposed outlet due to mowing and uv degradation	5-some nicking at exposed outlet, no undercutting or delamination, inside like new	5	5	5		

Louisiana

Additional Photos







APPENDIX 2 – CATEGORIZATION OF INSPECTED PIPES

This appendix includes the categorized grouping of the polymer coated inspected pipes. This chart contains the information that influenced the analysis found in Table 3. This table includes the 51 polymer coated pipes which were inspected as part of this project (5 of the inspected pipes were not polymer coated – 4 pipes in Upper Peninsula, Michigan one pipe in Wisconsin). Two pipes from Louisiana, LA-13 and LA-14, are included in this appendix but omitted from the analysis because of their unknown coating condition.

Pipe #	Age (Approx.)	Abrasion Level	Corrosivity	Coating Condition
AR-1	32	2	Low	5 (excellent)
AR-2	32	1	Low	5 (excellent)
AR-3	32	1	Low	5 (excellent)
AR-4	32	1	Low	5 (excellent)
AR-5	32	1	Low	5 (excellent)
AR-6	32	1	Low	5 (excellent)
AR-7	32	1	Low	5 (excellent)
LA-1	28	1	High	5 (excellent)
LA-2	28	1	High	4 (some delamination)
LA-3	16	1	Low	5 (excellent)
LA-4	16	1	Low	5 (excellent)
LA-5	16	1	Low	5 (excellent)
LA-6	18	1	Low	3 (moderate delamination with exposed metal)
LA-7	19	1	Moderate	5 (excellent)
LA-8	19	1	Moderate	5 (excellent)
LA-9	18	1	Moderate	5 (excellent)
LA-10	21	1	Low	5 (excellent)
LA-11	21	1	Low	5 (excellent)
LA-12	21	1	Low	5 (excellent)
LA-13	23	1	Moderate	Unk
LA-14	23	1	Moderate	Unk
MIB-1	33	1	Low	4 (some delamination)
MIB-2	33	1	Low	5 (excellent)
MIB-3	33	4	Low	3 (moderate delamination with exposed metal)
MIB-4	33	1	Low	4 (some delamination)
MIB-5	33	4	Low	5 (excellent)
MIB-6	33	4	Low	5 (excellent)
MIB-7	33	4	Low	5 (excellent)
MIU-1	33	2	Low	5 (excellent)

Pipe #	Age (Approx.)	Abrasion Level	Corrosivity	Coating Condition
MIU-4	33	2	Moderate	4 (some delamination)
NY-1	23	1	Low	5 (excellent)
NY-2	23	4	Moderate	4 (some delamination)
NY-3	22	3	Low	3 (moderate delamination with exposed metal)
NY-4	22	3	High	3 (moderate delamination with exposed metal)
NY-5	22	3	Low	3 (moderate delamination with exposed metal)
NY-6	22	1	Low	3 (moderate delamination with exposed metal)
NY-7	22	2	High	3 (moderate delamination with exposed metal)
NY-8	22	2	Low	4 (some delamination)
NY-9	22	2	Moderate	5 (excellent)
NY-10	22	2	Low	5 (excellent)
NY-11	22	3	Low	4 (some delamination)
NY-12	22	4	Low	4 (some delamination)
NY-13	22	1	Low	4 (some delamination)
NY-14	22	1	Low	4 (some delamination)
WI-1	28 - 38	1	Low	4 (some delamination)
WI-3	28 - 38	1	Low	5 (excellent)
WI-4	35	3	Low	5 (excellent)
WI-5	38	1	Low	5 (excellent)
WI-6	28 – 38	2	Low	5 (excellent)
WI-7	28 - 38	2	Low	5 (excellent)
WI-8	28 - 38	2	Low	5 (excellent)

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