Service Life Evaluation of Corrugated Steel Pipe
Storm Water Detention Systems in the Metropolitan Washington, DC Area

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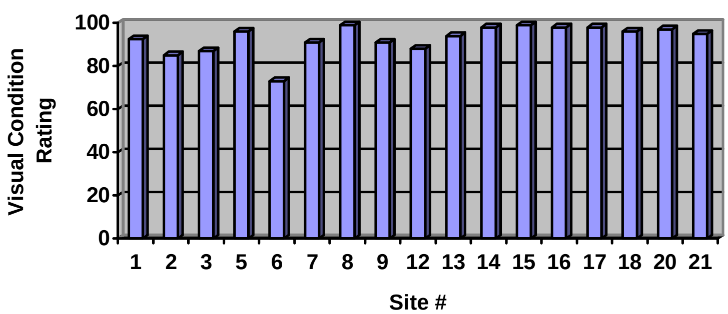
Abstract

This paper presents the results of an investigation of corrugated steel pipe (CSP) storm water detention systems (plain galvanized, aluminized, or bituminous coated) in the metropolitan Washington, DC area. This is a follow-up to a qualitative condition survey conducted by Parsons Brinkerhoff in 1998. This new work includes determining coating or metal loss and using available methodology to predict service life. The condition survey seems to support the conclusion that available service life prediction methods are generally conservative for storm water detention systems. This is reasonable given that the service life prediction methods were generally developed for culverts, which experience different service conditions (e.g., flow, abrasion) than detention systems.

Introduction

Detention facilities in new storm drainage systems are increasingly used to achieve urban drainage objectives. In areas where surface ponds are either not permitted or not feasible, underground detention may be used. Excess storm water is accommodated in some form of storage tank and discharged at a pre-determined rate into the sewer system or open water source. Detention systems can be constructed from corrugated steel pipe.[1]

Corrugated steel pipe (CSP) storm water detention systems (plain galvanized, aluminized, or bituminous coated) have been in use in the metropolitan Washington, DC area since the early 1970s. A qualitative condition survey to assess the overall performance of 17 of these systems was conducted by Parsons Brinkerhoff on behalf of the National Corrugated Steel Pipe Association (NCSPA) in early 1998. The overall conclusion of the survey[2] was that the systems were performing extremely well. Figure 1 shows the average condition rating (crown, sides, invert) based on a visual rating scale.[3] Most systems still had the zinc layer intact after about 25 years of service. There were no signs of visible deflection and most joints appeared to be soil tight.



Rating	Description
100-95	
90	Galvanizing intact
80-85	
75	Galvanizing partly gone,
60-55	some rust
50	Galvanizing gone,
45-40	significant metal loss
35-30	
25	Deep pits, heavy metal
20-15	loss, perforation
10-5	
0	Major metal loss

FIGURE 1 Condition Rating of Corrugated Steel Pipe Detention Systems

In May of 2000 the NCSPA retained Corrpro Companies Inc. to perform a more detailed and quantitative evaluation of the corrugated steel pipe storm water detention systems evaluated previously. This work includes determining coating or metal loss and using available methodology to predict service life. This paper presents some findings of the work as they related to service life prediction.

Evaluation Procedures

Twelve of the original 17 sites were available for evaluation. Sites 15 and 20 are sand filter systems and were not evaluated because access to the invert would require removal of sand filter media. During the field inspection it was found that one of the systems (Site No. 12) had been removed during redevelopment. In addition, it was not possible to gain access to two of the systems, sites 1 and 18. Table 1 presents an overview of each inspected site including the numbering, location, land use, system size, age, and sampling performed at each of the sites.

TABLE 1 Stormwater Detention System Overview

Site No.	Location	Dia. (in)	Coating	Corrugation	Age (yrs)	Samples Collected		
						Soil	Water	Coupons
2	Industrial, Montgomery County, MD	48	Galvanized	1x3" Helical	26	2	2	3
3	Industrial, Montgomery County, MD	48	Galvanized	1x5" Helical	26	1	2	2
5	Industrial, Montgomery County, MD	60	Galvanized	1x5" Helical	21	2	2	2
6	Commercial, Montgomery County, MD	96	Galvanized	1x5" Helical	21	2	2	2
7	Commercial, Montgomery County, MD	96	Galvanized	1x5" Helical	21	2	2	2
8	Commercial, Montgomery County, MD	72	Fully Bituminous Coated	1x5" Helical	21	2	2	2
9	Commercial, Montgomery County, MD	72	Galvanized	1x5" Helical	21	2	1	2
13	Commercial, Montgomery County, MD	108	Aluminum Coated Type 2	1x5" Helical	11	1	1	2
14	Residential, Fairfax County, VA	67x104	Fully Bituminous Coated	1x5" Helical	6	2	1	2
16	Residential, Fairfax County, VA	80	Aluminum Coated Type 2	1x5" Helical	11	1	2	2
17	Residential, Fairfax County, VA	65x107	Fully Bituminous Coated	1x5" Helical	6	1	2	2
21	Residential, Alexandria, VA	144	Galvanized	1x5" Helical	6	1	2	2

Field-testing consisted of performing visual observations, in-situ measurements of soil resistivity, soil pH, and redox potential at each site. Wherever possible, photographic documentation of the detention systems was made. Disk coupons (1½ inch in diameter) were obtained from the top or side and invert at each location for subsequent determination of the remaining zinc layer thickness. An extra coupons was taken at Site 2 based on field observations (visual and coating thickness gage) indicating areas of higher coating loss. A total of 25 coupons were collected.

Soil and water samples were also collected from each site for laboratory analysis. Soil samples were removed through the hole left when the coupon was taken. In six of the locations, it was not possible to remove a soil sample. Water samples were taken from inside the detention system whenever possible.

Samples collected from the field-testing were evaluated in the laboratory. Corrugated steel pipe coupons were polished metallographically along their thickness and etched to reveal the zinc layer. The zinc layer thickness was measured at ten locations (evenly-spaced along the edge) on both the water- and soil-side of the coupon with the help of a low-powered optical microscope and an average thickness was calculated. Minimum overall thickness (steel plus zinc coating) was also measured on each coupon using a digital micrometer. Soil samples were evaluated to identify the soil type and physical characteristics, determine resistivity, pH, moisture content, chlorides and sulfides. Water samples were evaluated to determine pH, resistivity, chlorides, and sulfides.

Utilizing the soil and water analysis data, the predicted service life of the detention system was calculated using a three methods:

- Software previously developed by Corrpro Companies for the NCSPA.[2]
- California Method for Estimating Years to Perforation of Steel Culverts
- AISI Method for Service Life Prediction

Findings

Table 2 summarizes the results of the soil resistivity, pH and potential measurements made at each site. Over 80% of the potential readings were found to be in the range of –617 mV to –946 mV with respect to a copper-copper sulfate electrode. Potential readings in this range indicate that the galvanized layer has not corroded away and exposed the bare steel. Visual observations of the coupons show that water-side and soil-side coating deterioration is quite similar.[4] There is no significant water-side invert deterioration, perhaps in part due to an absence of abrasion in the invert of detention systems. The invert of the detention systems is typically silted or stagnant water, thus oxygen access is limited.

TABLE 2 Field Test Data

		Soil Resistivity*		Potential, mV vs. CSE**			pH	
Site No.	**Location**	**Bottom**	**Top**	**Bottom**	**Top**	**Surface**	**Bottom**	**Top**
Galvanized Systems								
2	Industrial, Montgomery County, MD	4000	7000	-681	-637	-508	6.85	6.74
3	Industrial, Montgomery County, MD	4000	4000	-562	-620	-549	NM	NM
5	Industrial, Montgomery County, MD	6500	11000	-644	-694	-633	NM	8.14
6	Commercial, Montgomery County, MD	13000	6000	-786	-740	-689	6.85	6.83
7	Commercial, Montgomery County, MD	20000	3300	-741	-546	-722	7.24	7.86
9	Commercial, Montgomery County, MD	50000	NM	-641	-690	-724	NM	7.38
21	Residential, Alexandria, VA	NM	1900	-629	-706	-671	6.27	6.49
Fully Bituminous Coated Systems								
8	Commercial, Montgomery County, MD	20000	2000	-938	-721	-946	NM	NM
14	Residential, Fairfax County, VA	11000	7100	-973	-481	-955	7.14	8.67
17	Residential, Fairfax County, VA	15000	6000	-926	-946	-933	7.16	6.8
Aluminum Coated Type 2 Systems								
13	Commercial, Montgomery County, MD	10000	5500	-664	-672	-425	10.4	10.1
16	Residential, Fairfax County, VA	NM	28000	-617	-665	-613	7.81	8.01

*Soil resistivity determined with a Collins Rod
**CSE = copper sulfate electrode
NM - Not Measured

Analysis and Discussion

Table 3 summarizes the laboratory analysis data for the soil samples used to calculate the remaining life of the galvanized layer using the software program previously developed by Corrpro for NCSPA.[2] The software generates service life predictions from a statistical model developed to accurately predict service life of galvanized CSP for sites where durability is limited by soil side corrosion. The model predicts the condition of the protective galvanized coating over time plus the life of 16 gage black steel. According to the author:

> "When the galvanized coating reaches the point that pitting of the steel substrate could begin, the model uses black steel corrosion data from 23,000 black steel underground storage tank sites to analyze overall durability vs. time. The black steel used in the model was 16 gage. Therefore the model does not accommodate added life projections due to the increased thickness of the pipe wall. Use of this data induces significant conservatism also, because, it is based on steel not previously galvanized, and therefore, does not recognize the effects of residual galvanizing and the alloy layer formed during the galvanizing in slowing the corrosion process. Additionally, the slowing of the corrosion pitting rate with time for thicker gages cannot be accommodated. However, these shortcomings add conservatism to the service life estimates."

The calculations show the average predicted life of a 16 gage galvanized pipe in these environments is about 86 years. Table 3 also attempts to adjust the service life prediction by using a gage multiplier as recommended by the AISI Method. This shows that the average predicted life of the systems is about 130 years. The minimum predicted service life for any of the systems is 65 years. Taking all of the above factors into consideration, the average service life prediction made using the software for predicting soil-side service life would be in excess of 100 years. This is consistent with the previous studies conclusion that "93.2% of the plain galvanized installations have a soil side service life in excess of 75 years, while 81.5% have a soil side service life in excess of 100 years."

TABLE 3 Laboratory Soil Analysis Data and Soil Side Life Prediction*

Site No.	**Sample Loc'n**	**Soil Type**	**Sample Color**	**Moisture %**	**pH**	**Chloride ppm**	**Sulfide ppm**	**Resistivity ohm-cm**	**16 ga galvanized pipe life yrs***	**Gage Multiplier**	**Predicted Pipe Life yrs**
Galvanized Systems											
2	Top	sandy clay loam	gray	23.72	7.4	16	0.3	722	91.5	1.0	91.5
	Invert	clay	gray-brown	27.32	7.7	60	0	1684	70.9	1.0	70.9
3	Top	clay	gray	29.14	7.9	32	0	2538	100.1	1.0	100.1
5	Top	silty loam	gray-brown	23.83	7.9	20	0	8696	141.4	1.3	183.8
	Invert	clay	gray-brown	26.51	7.4	27	0	3663	91.7	1.3	119.2
6	Top	silty clay	light red brown	27.52	6.4	37	0	4630	57.4	1.3	74.6
	Invert	silty clay	light red brown	29.18	6.8	28	0.3	5051	67.7	1.3	88.0
7	Top	silty clay loam	light red brown	23.67	6.3	42	0	2941	50.4	1.3	65.5
	Invert	silty clay loam	light red brown	30.21	6.6	9	0	11765	122.9	1.3	159.8
9	Invert	clay	gray-red brown	34.00	7.6	10	0	2899	139.7	2.3	321.3
21	Top	silty clay	light red gray	24.17	6.0	34	0	1992	45.4	1.8	81.7
Fully Bituminous Coated Systems											
8	Top	silty clay loam	yellow gray	25.58	7.7	32	0	2899	94.9	1.3	123.4
	Invert	silty clay loam	yellow gray	27.48	7.6	30	0	3846	96.8	1.3	125.8
14	Side	silty clay loam	light gray brown	23.07	5.7	10	0	7813	79.9	1.8	143.8
	Invert	caliche	light gray brown	32.38	6.6	10	0	10417	115.9	1.8	208.6
17	Invert	silty clay	light red brown	27.95	5.1	12	0	6993	59.3	1.8	106.7

TABLE 3 (continued) Laboratory Soil Analysis Data and Soil Side Life Prediction*

Aluminum Coated Type 2 Systems										
13	Side	silty clay	light red brown	26.73	6.6	30	0	1961	60.6	2.3	139.4
	Invert	silty clay	light red brown	34.33	7.2	18	0	3745	100.1	2.3	230.2
16	Top	silty loam	light gray brown	20.40	4.9	16	0	10417	54.0	1.3	70.2

*Service life for 16 gage galvanized pipe using software previously developed by Corrpro for NCSPA

Table 4 shows the predicted service life of each detention system using both the California and AISI methods. The California Method was developed by Stratful to predict time to fist perforation, which is not considered the end of service life. The AISI Method (also developed by Stratful) is based on the Caltrans Method but is used to predict average invert service life.[5]

For each method, the service life was calculated independently for each of the environmental samples (soil and water). The minimum of the calculated values for each pipe is also identified in the table. Notice that systems 2, 3, and 7 are very near the end of the California Method predicted service life (first perforation). Yet the systems are all in quite good condition, with most of the galvanized coating still in tact. Note that the soil-side prediction is worse than the water-side prediction in 8 of 12 instances. In 10 of 12 instances the AISI predictions for the various environments have a coefficient of variation less than 35%. This demonstrates that the predictions of service life are not strongly tied to either water- or soil-side conditions.

TABLE 4 Service Life Predictions in Accordance with the California Method and AISI Method

Site No.	Sample Location	pH	Resistivity, ohm-cm	Gage	California Pred. Life, yrs	AISI Pred. Life, yrs	Minimum California	Minimum AISI
Galvanized Systems								
2	Crown Soil	7.4	722	16	28	57	28	57
	Invert Soil	7.7	1684		40	80		
	Water*	5.5	613		5	10		
3	Crown Soil	7.9	2538	16	48	95	31	62
	Water**	7.5	881		31	62		
5	Crown Soil	7.9	8696	14	97	205	34	73
	Invert Soil	7.4	3663		68	144		
	Water	7.4	692		34	73		
6	Crown Soil	6.4	4630	14	33	69	32	67
	Invert Soil	6.8	5051		39	82		
	Water	6.2	5181		32	67		
7	Crown Soil	6.3	2941	14	27	58	27	58
	Invert Soil	6.6	11765		44	93		
	Water	7.3	3165		55	116		
9	Invert Soil	7.6	2899	10	108	231	94	201
	Water	7.9	2066		94	201		
21	Crown Soil	6.0	1992	12	29	61	29	61
	Water	6.2	8333		50	106		

TABLE 4 (continued) Service Life Predictions in Accordance with the California Method and AISI Method

Fully Bituminous Coated Systems								
8	Crown Soil	7.7	2899	14	62	130	62	130
	Invert Soil	7.6	3846		69	147		
	Water	7.6	3135		64	135		
14	Side Soil	5.7	7813	12	44	94	44	94
	Invert Soil	6.6	10417		59	125		
	Water	6.9	4184		54	114		
17	Invert Soil	5.1	6993	12	38	80	38	80
	Water	6.6	12195		61	130		
Aluminum Coated Type 2 Systems								
13	Side Soil	6.6	1961	10	47	100	47	100
	Invert Soil	7.2	3745		84	179		
	Water	7.3	4016		100	214		
16	Crown Soil	4.9	10417	14	30	64	30	64
	Water	6.8	5814		40	85		

Notes: 1. The above resistivity and pH data was obtained from laboratory analysis of field samples.
2. All predictions are for galvanized pipe of the designated gage. No multiplier or "add-on" for additional coating has been used
*This water smelled of antifreeze. It was considered an aberrant condition for service life prediction.
**This "water" was saturated with organic matter.

To better understand the relationship between the California Method predictions and existing conditions, Potter correlated percent penetration with percent of California predicted service life expended.[6] While there has been extensive debate over the validity of the technique, it is used here to compare service life predictions. Table 5 presents the minimum overall metallic thickness (steel plus metallic coating) measured on all coupons from each system. That value is compared with the "original" thickness. The original thickness was determined in most cases by measuring overall thickness on the crown of the pipe where the metallic coating was metallographically determined to be intact at nominally the original thickness. System 6 was the only system where an original thickness was difficult to determine, but a sufficiently conservative estimate was made based on measurements of the coupons. Figure 2 shows the data plotted in a manner similar to that used by Potter. Best-fit lines were regressed through all of the data for galvanized and asphalt coated pipes. No plot was made for aluminum coated pipes due to a lack of sufficient number of data points.

Using all data points, the analysis suggests that the galvanized systems are performing 2.8 times as well as the California Method would predict while the fully bituminous coated systems are performing 4.6 times as well as the California Method would predict for galvanized material. It should be noted that this multiplier increases to 7.3 times for galvanized systems if Site #6 is ignored. The data collected from these detention systems support the conclusion that the galvanized detention systems will last longer than the California Method would predict for culverts.

TABLE 5 Service Life Analysis Using the Technique Developed by Potter

	Thickness - inches				Actual Age	
Site No.	Original (est)	Min from all coupons	Percent Perforation	Min. Calif Pred. Years**	Years	Percent of Calif. Pred.
Galvanized Systems						
2	0.058	0.048	17.2%	28	26	92.9%
3	0.058	0.056	3.4%	31	26	83.9%
5	0.072	0.069	4.2%	34	21	61.8%
6	0.071	0.044	38.0%	32	21	65.6%
7	0.071	0.068	4.2%	27	21	77.8%
9	0.128	0.126	1.6%	94	21	22.3%
21	0.099	0.097	2.0%	29	6	20.7%
Fully Bituminous Coated Systems						
8	0.075	0.071	5.3%	62	21	33.9%
14	0.098	0.096	2.0%	44	6	13.6%
17	0.105	0.099	5.7%	38	6	15.8%
Aluminum Coated Type 2 Systems						
13	0.124	0.120	3.2%	47	11	23.4%
16	0.070	0.053	24.3%	30	11	36.7%

** Data from Table 4 of this report

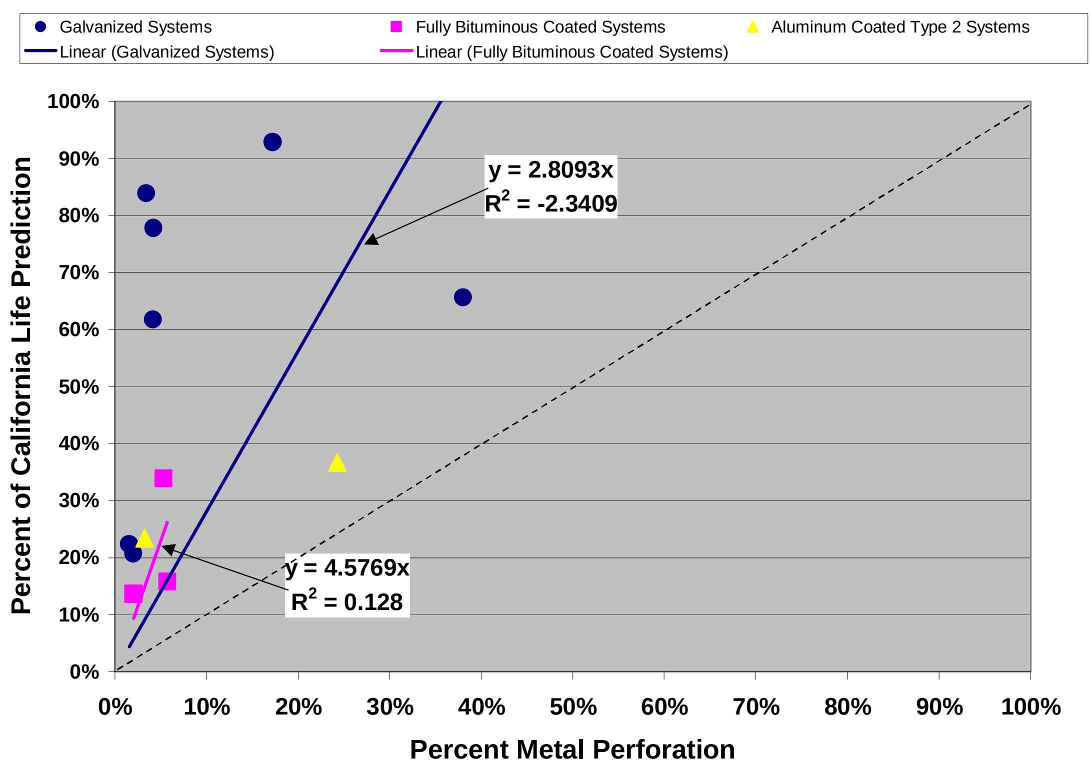


Figure 2. Percent Metal Perforation vs. California Prediction

It is not surprising that the AISI and California Method would under-predict the service life of storm water detention systems constructed from corrugated steel pipe. The California Method was developed based on observations of

7,000 corrugated metal culverts located in California. The AISI method was developed based on the California Method. Both methods have culverts as their basis. The population of culverts certainly included pipe subject to conditions that would be more extreme than a detention system would experience. Detention systems by function are cyclically wet but predominately dry. In some cases the invert may see long periods of exposure to stagnant water. The population on which the service life projection methods were based certainly included pipes which are typically full of flowing water or subject to abrasive influences – both more corrosive situations.

The California method defines service life as the time to first perforation while the AISI method limits useful service life to a 25% metal loss. Stormwater detention systems by design let water back into the surrounding soil. In fact, some systems are developed with slotted pipe (undesirable from a corrosion perspective as the cut edges corrode quicker than the coated material). Functional service life for a detention system could be defined as the time until structural failure. This definition would intuitively take one beyond the criteria used in the development of the AISI prediction technique.

Conclusions

1. Corrugated steel pipe storm detention systems with various coatings (galvanized, aluminized, or bituminous coated) observed in this study are performing satisfactorily in service.

2. From the data collected in this study (12 systems), both the AISI Method and the California Method provide conservative service life predictions for corrugated steel pipe used in stormwater detention systems.

3. Physical inspection of these systems suggests that they will perform longer than standard methods for predicting the service life of culverts predict. The analytical approach presented herein support the prediction of a functional service life for the galvanized detention systems in excess of 100 years.

References

[1] *Modern Sewer Design*, National Corrugated Steel Pipe Association, Washington, DC, 1999.
[2] *Condition Survey of Corrugated Steel Pipe Detention Systems*, National Corrugated Steel Pipe Association, Washington, DC, March 1999.
[3] *Condition and Corrosion Survey: Soil Side Durability of CSP*, Corrpro Companies, March 1991.
[4] *Service Life Evaluation of Corrugated Steel Pipe Storm Water Detention Systems in the Metropolitan Washington, DC Area*, National Corrugated Steel Pipe Association, Washington, DC, March 2002.
[5] *Durability of CSP*, Richard Stratful, Corrosion Engineering, Inc., 1986.
[6] *Durability of Special Coatings for Corrugated Steel Pipe*, J.C. Potter, I Lewandowski, and D.W. White, Federal Highway Administration, Report No. FHWA-FLP-91-006, June 1991.