ACKNOWLEDGMENT

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Durability of Asphalt Coating and Paving on Corrugated Steel Culverts in New York

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ABSTRACT

The metal-loss rate of uncoated corrugated steel pipe in New York State has been well-defined. To complete a design procedure for coated-and-paved corrugated steel pipe, paving life also had to be defined. A method developed to determine the effectiveness of paving by measuring the longitudinal percentage of exposed metal is described in this paper; 294 coated-and-paved pipes were surveyed and measured. In New York State paving has effectively protected round pipe on the state system for 30 years and pipe-arches for at least 20 years. Beyond 30 years, paving is ineffective in protecting any corrugated steel pipe.

Corrugated steel is one of the most commonly used materials for culverts in New York State and throughout the country. There has been concern for many years about the durability of this material. New York recently completed a long-term durability study of uncoated galvanized corrugated steel pipe (1). [All corrugated steel pipe (CSP) is galvanized with a coating of zinc to improve its resistance to corrosion.] This study provided corrosion (metal-loss) rates for uncoated CSP. By using these corrosion rates, many CSPs would not last the desired design life. Thus additional protective measures are needed.

One of the most common protective measures is an asphalt coating, which is applied by dipping the pipe sections in a tank of hot asphalt. The resulting coating dries to a thickness of about 0.05 in. on both the interior and exterior of the pipe. Some states use the coating mainly as a protection for the exterior or soil side of the pipe. New York has found little soil-side corrosion in its studies. A previous New York study (2) indicated that interior asphalt coatings alone are not effective in preventing corrosion, and New York has not used them alone for the past 17 years.

Azar (3) found that coating gave an additional 8 years of service. A Kansas study by Worley (4) of 500 coated pipes revealed that inside coatings were good on only 12 percent of 3- and 4-year-old pipes and on none of the older ones. It was concluded that Kansas should discontinue the use of coatings because they are of little value. A survey of the other 49 states in the summer of 1978 (5) indicated that few states use coated pipe, and those that do use it assign only 7 to 9 additional years of life for the coating.

In addition to asphalt coating, paving of asphalt can be applied to the interior of the pipe. This is normally at least 0.125 in. thick over the crests of the corrugations, thus providing a smooth surface over the length of the pipe. It is generally placed in the lower quadrant of the pipe to protect the invert (i.e., the lowest point where water flows through the pipe).

Paving is applied to a coated pipe by partially blocking its ends and pouring asphalt in the bottom. The pipe is rotated and the process is repeated until the bottom quarter of round pipes and the bottom 40 percent of pipe-arches are covered. This process results in a feathering out of the paving at the paving-coating interface. This area is particularly susceptible to corrosion and abrasion when the flow extends to or above the interface level. Occasionally, paving is specified for the entire bottom half of the pipe when high flows are anticipated. In 1965 Berg (6) recommended paving the bottom half of round pipe, and in 1982 Meacham et al. (7) recommended paving the bottom third of round pipe and the bottom 45 percent of pipe-arches.

[Fully paved pipe (paving around the entire circumference) is used for closed systems (storm sewers) to increase the hydraulic efficiency of the pipe. In this case paving is centrifugally applied by spinning to fill and cover the inside corrugations to 0.125 in. over the crests for the entire circumference. Fully paved pipe was not included in this study.]

New York has recently completed a series of field and laboratory tests to provide better information on uncoated pipe life (1). Through this work a procedure was developed for extracting and measuring metal coupons. Data collected statewide on 190 uncoated culverts has provided New York with accurate information for design purposes. By combining these findings with the life of coating and paving to be determined in this study, the total life of coated-and-paved CSP can be predicted.

FIELD SURVEY

Method

Manufacturers, state transportation agencies (including New York's), and FHWA have all (at one time or another) evaluated the durability of coated-and-paved pipe (8). These evaluations have involved either rating systems or visual estimates of the amount of coating and paving removed from the culverts, which resulted in exposure of bare metal. New York has previously used visual estimates of coating-and-paving loss.

Although rating systems and visual estimates give an indication of coating-and-paving loss, they are subject to errors introduced by the observer, either systematic errors or bias. In addition to the measurement errors involved, there is the problem of determining exactly what to measure. Consider first the ways in which loss can be measured for just the paved invert (the bottom quarter of a round culvert). One possible measurement is to determine the remaining thickness of the asphalt paving. Because of the variable thickness of the material, depth of paving over the corrugated profile would be extremely difficult to characterize throughout the length of the culvert. Not only are the measurements difficult and time-consuming, but the original thickness of paving cannot be ascertained accurately. This would make it nearly impossible to project rates of loss.

In addition, experience in New York has indicated that paving does not fail by eroding away (losing thickness), but instead by removal of the entire paving and coating to the bare metal. Coating and paving act as one system; thus when paving is lost, the coating underneath is lost at the same time and bare metal is exposed. Thus the easier and perhaps more important measurement would be the extent of exposed bare metal. The ultimate failure point of coating and paving is when it no longer covers the surface it is supposed to protect.

The extent of exposed bare metal can be measured in several ways. One is to determine the area of bare metal with respect to the entire area of paving, which can have serious drawbacks in characterizing the extent of failure. For example, assume the width of paving in a pipe is 25 in. measured along the circumference. If a 4-in.-wide area of bare metal is exposed for the entire length of the culvert, this would represent 16 percent of the total paving area. Yet in that continuous area throughout the pipe the metal is 100-percent exposed to corrosion or abrasion or both. In effect, this is a complete failure of the paving. Thus a more desirable measurement would be the length of exposed metal along the longitudinal axis of the pipe, expressed as a percentage of the total length.

In some cases paving may be removed in chunks at random locations on the paved invert area. Again, the actual percentage of metal exposed in the paved area would appear to be less important than the length of pipe exposed, expressed as a percentage of the total length of the culvert. The same reasoning can be applied to the coated portion of the pipe above the paving. Once the total length of pipe is exposed, regardless of the width of exposure, the coating can be considered completely ineffective. Thus for purposes of this study, the condition of coated-and-paved pipe was based on measurements of the longitudinal length of exposed metal within each pipe. In cases where areas of exposure are not along the same longitudinal line, the longitudinal lines of exposure were added to determine the maximum exposed length (see Examples 2 and 3 and Figures 2 and 3). The following three examples will help clarify the technique:

1. Example 1 (Figure 1): A common occurrence was loss of both coating and paving at the flow line (often at the coating-paving interface) for the entire length of the culvert. This would be 100 percent loss of coating. Paving loss in this example is more difficult to define because the loss at the coating-paving interface may be due only to the thin

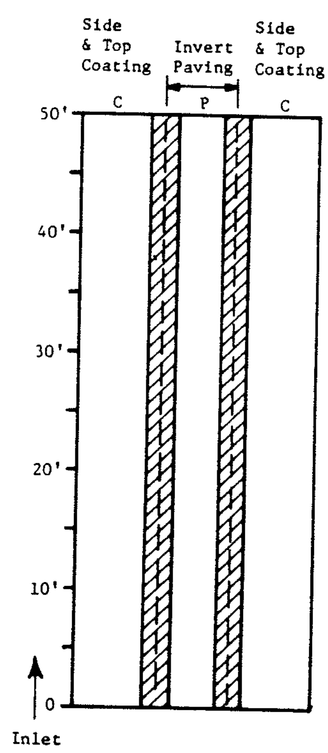

FIGURE 1 Coating and paving removed at interface.

feathering out of the paving, as discussed earlier. Interpretation of this case will be discussed in detail later in this paper.

2. Example 2 (Figure 2): Paving removal may not be continuous and may not be in the same longitudinal line throughout the length of the culvert. In this case none of the coating is removed, but paving is removed in two distinct longitudinal lines. Line 1 is removed from 0 to 10 ft and 35 to 40 ft, and Line 2 is removed from 5 to 25 ft and 45 to 50 ft. Combining the two lines, the paving is removed from 0 to 25, 35 to 40, and 45 to 50 ft, or a total of 35 ft of the 50-ft length. This would be reported as a 70 percent loss of paving.

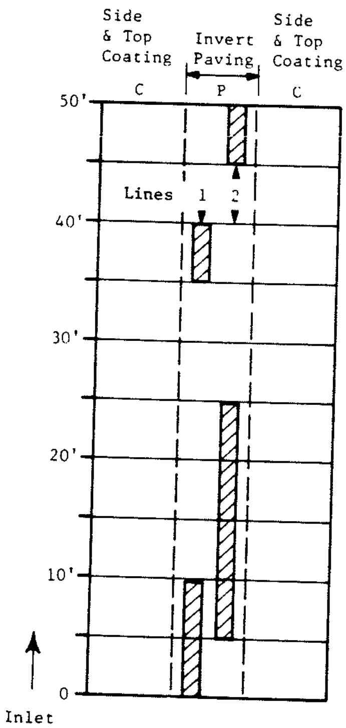

FIGURE 2 Only paving removed.

3. Example 3 (Figure 3): Some cases have both paving removal in the invert area and coating-and-paving removal in the interface areas. Applying the rules outlined earlier, coating is removed from 0 to 25 ft and 45 to 50 ft, or 30 ft of the 50-ft length (60 percent loss). The combined paving loss is from 0 to 35 ft and 45 to 50 ft, or 40 ft of the 50-ft length (80 percent loss).

Supplemental Measurements and Observations

In addition to measuring coating-and-paving loss, numerous other measurements and observations were made. Recorded information included sample number, culvert number (a number from previous New York studies of the culvert), county, region (New York State Department of Transportation (NYSDOT) has 11 regional offices), location description, milepost number, diameter (for round culverts), span and rise (for pipe-arch culverts), length, age, culvert use (stream or ditch collector), and bedload (type of material inside the pipe and in the inlet channel). Pipe slope and inlet slope were measured with a hand level and a 5-ft rod. The bearing of the pipe was taken with a compass.

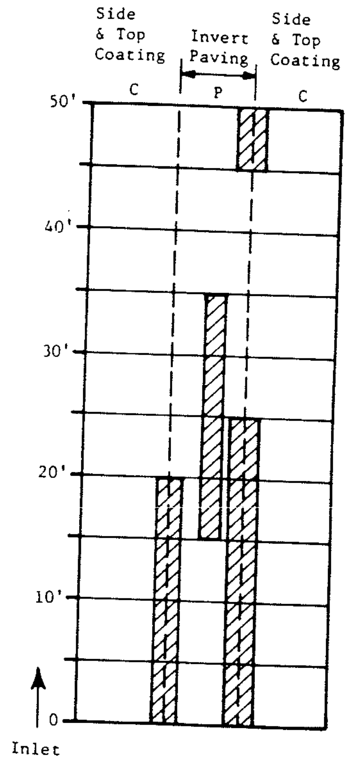

FIGURE 3 Combination of both types of loss.

Sample Size

Uncoated, coated, and coated-and-paved corrugated metal pipes were surveyed visually statewide in 1965. More than 400 coated-and-paved pipes were examined, of which 280 were at least 30 in. in diameter (the smallest diameter that can be examined for its entire length by a field crew) and were included as potential candidates for this study. In 1977 each county highway office in the state was visited to obtain potential candidates for the uncoated pipe study (1). Many pipes were found to be coated and paved--not uncoated. An additional 130 potential candidates (30 in. in diameter or larger) were selected.

These two sources combined totaled 410 potential study candidates. All were inspected and 294 were eventually included as part of the study. The number was reduced from 410 because of heavy water flow or debris that prevented inspection of many pipes. Also, coating measurements were obtained for all 294 pipes, but paving measurements were obtained for only 272 because of the field conditions just noted.

Sample Distribution

The 294 pipes are well distributed at 121 sites throughout the state under a variety of environmental conditions. They ranged in age from 9 to 47 years; the bulk (262) were from 11 to 30 years old. Only 37 pipes were 15 years old or less, and 8 were 10 years old or less.

This sampling was analyzed for three major variables in addition to age: zone, system, and shape. Data for metal loss of uncoated pipe (1) produced two distinct zones of metal loss rates in New York State--Zone 1 (northern) and Zone 2 (southern), as shown in Figure 4. The corresponding annual metal-loss rates were 2 mils in Zone 1 and 4 mils in Zone

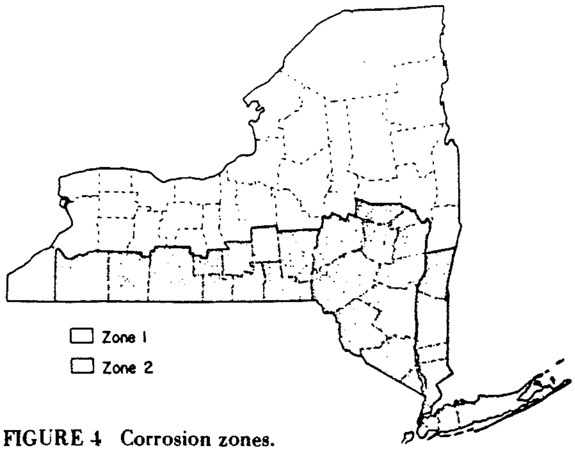

FIGURE 4 Corrosion zones.

FIGURE 5 Flow line loss.

FIGURE 6 Invert loss.

2. It was thought that coated-and-paved pipe might follow these same or similar zones.

Pipe distribution by zone, system, and shape is given in the following table:

	Coated and Paved (n=272)	Coated (n=294)
Zone 1	151	159
Zone 2	121	135
Round	191	203
Pipe-arch	81	91
County	107	116
State	165	178

Referring to the paving column, note that more pipes are in Zone 1 (151) than in Zone 2 (121). More than twice as many are round (191) than pipe-arch shape (81), and more are on the state (165) than county (107) systems.

DATA ANALYSIS

Failure Types

Analysis of the field data sheets revealed five general failure types for coated-and-paved pipe:

1. Coating loss only above the coating-paving interface: The interface was previously discussed. Culverts in New York often carry enough water so that the flow line is above the paving. Thus the only loss is in the coating.

2. Coating and paving loss at the coating-paving interface: This occurs when flow is at or very near the coating-paving interface, and consists of coating loss with only a small portion of the paving removed at the interface (Figure 5). Paving loss may be caused by the flow, but also by thin paving at the interface, bond problems, or careless paving installation practices. In both Types 1 and 2 of loss, the invert paving may be intact, partially gone, or too much water or debris may be present for any determination.

3. Complete paving removal: In this case all paving is removed to the limit of the flow. When the paving is removed, the coating beneath it is also removed to the bare metal. Thus when "paving removal" is referred to in the following discussion, removal of the underlying coating is implied. Figure 6 shows an example of complete paving removal.

4. Paving loss at the flow line within the paving: If the predominant flow in the pipe does not extend beyond the paved area, losses appear to occur in two ways. In this case loss of paving is most evident at the extremities of the flow.

5. Paving loss at the invert: When the flow does not extend beyond the paved area, the other type of loss occurs predominantly at the invert rather than at the flow line.

In many instances more than one type of loss occurred. For instance, when the flow line extended beyond the limits of paving, the coating was completely removed in virtually all cases. However, other forms of loss such as partial paving removal at the invert sometimes occurred as well.

As mentioned earlier, use of coating without invert paving has been discontinued in New York. The results of this study confirm that when water flows above the paved area of the pipe, the coating is nearly 100 percent removed for all age groups.

Samples Analyzed

During the field inspection phase of this project 294 pipes were inspected, yielding 272 pipes with paving data. No paving data were gathered for the remaining 22 pipes because of high water or debris. The number of pa[illegible] pipes was further reduced by using a single [illegible] for double and triple installations. In mo[illegible] es [illegible] s for double and triple installations [illegible]; the worst case was

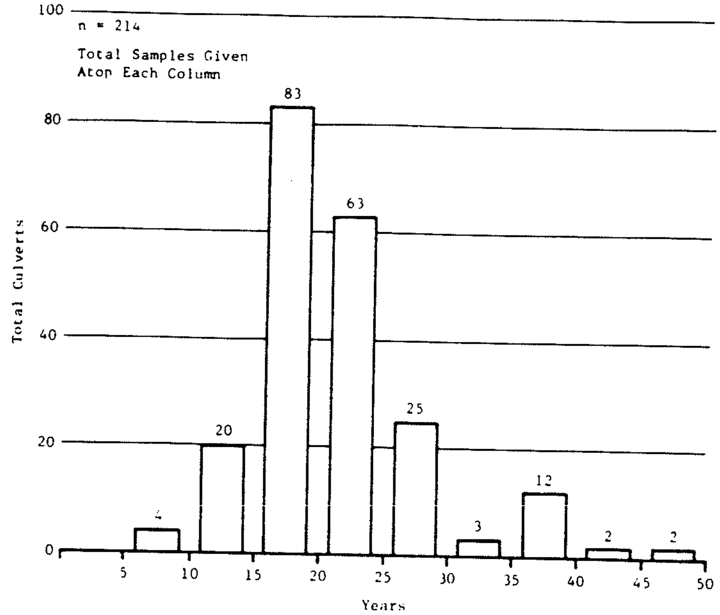

FIGURE 7 Age distribution.

used when they were not. These eliminations reduced the number of paved pipes analyzed to 214.

The age distribution of these 214 pipes is shown in Figure 7. Their comparison with the original 272 indicates that the two age distributions are similar (Table 1). All further discussion will concern only the 214 pipes. The distribution of these pipes into zones, system, and shape is given in Table 2.

TABLE 1 Paving Age Distribution

Age Group (years)	272 Culverts		214 Culverts[a]	
	Total	Percent	Total	Percent
0-5	0	0	0	0
6-10	7	3	4	2
11-15	28	10	20	9
16-20	101	37	83	39
21-25	77	28	63	29
26-30	30	11	25	12
31-35	5	2	3	1
36-40	20	7	12	6
41-45	2	1	2	1
46-50	2	1	2	1

[a]The number of culverts was reduced by eliminating culverts with debris, and doubles and triples (these were counted as one—the worst one if there was a difference).

TABLE 2 Distribution of Pipes

Age Group (years)	Total	Zone		System		Shape	
		1	2	State	County	Round	Pipe-Arch
6-10	4	2	2	0	0	2	2
11-15	20	4	16	3	17	11	9
16-20	83	51	32	66	17	53	30
21-25	63	42	21	45	18	50	13
26-30	25	14	11	13	12	22	3
31-35	3	0	3	0	3	1	2
36-40	12	7	5	3	9	12	0
41-45	2	2	0	1	1	2	0
46-50	2	2	0	0	2	2	0
Total	214	124	90	131	83	155	59

Variables

Four major variables may influence the rate of paving loss--age, zone, system, and shape--and each was analyzed for the 214 pipes.

Age

The most obvious and one would think the most significant variable is age. Figure 7 shows the age distribution of the 214 culverts in 5-year increments. Most (192) are from 11 to 30 years old. Only 24 pipes are 15 years old or less, with 3 the youngest at 9 years. Average percent loss of paving versus age in 5-year increments is shown in Figure 8. The expected trend of increasing loss with age is not supported by these data. Percent loss with age increases from 16 to 30 years, but in the 6 to 10 and 11 to 15 age groups losses are high. When the average percent loss versus age in individual years was plotted, the expected trend of increasing percent loss with age was even less apparent.

Zone

As mentioned and shown earlier (Figure 4), the distribution of metal-loss rates for uncoated CSP followed two distinct zones--a northern zone (Zone 1) with a metal-loss rate of 2 mils per year, and a more severe southern zone (Zone 2) with an annual rate of 4 mils. There was no clear-cut evidence of a difference in performance of paving by zone, and paving loss rates were fairly consistent between zones.

System

The culverts used for this study were from both state and county systems, and the method of selecting candidate culverts has already been explained. Figure 9 shows the average percent paving loss versus age in 5-year increments for each system, plotting only to 30 years when paving is essentially 100

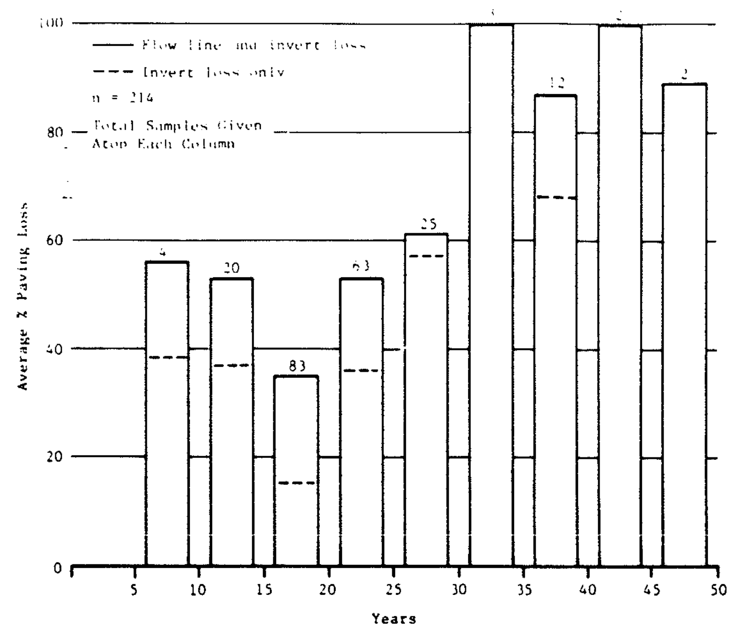

FIGURE 8 Average paving loss in 5-year increments (n = 214).

percent lost for both the state and county systems. This graph shows a difference for the two systems. In four of the five age groups (there are no state pipes in the 6- to 10-year-old group), average percent loss is greater for county than state pipes.

Combining the first five age groups (6 to 30 years), the average loss is 39 percent for 127 state pipes and 64 percent for 68 county pipes. Several possible explanations were found for this:

1. The sample size is smaller for county pipes.
2. The county pipes may be at more severe sites. State pipes are often on new construction where drainage is hydraulically designed and the drainage pattern is improved, whereas county pipes are often placed at natural, unimproved sites.
3. County sites may carry more water than state sites.
4. Pipe specifications may be different for the counties than for the state.
5. Most state pipes are installed under contract, and are usually purchased from the manufacturers soon after paving. County pipes may be stored in county maintenance yards for long periods and paving may deteriorate with heat, cold, or time.
6. Counties use more pipe-arches, which have a greater average percent loss than round pipes.

Any, all, or perhaps none of these explanations may explain the difference. The last was studied in more detail because it was thought that the difference might be in shape (round or pipe-arch) rather than system (state or county).

Shape

Figure 10 shows the average percent paving loss versus age to 30 years (in 5-year increments) for shape. In three of these five critical age groups, pipe-arches have higher losses than round pipes. For

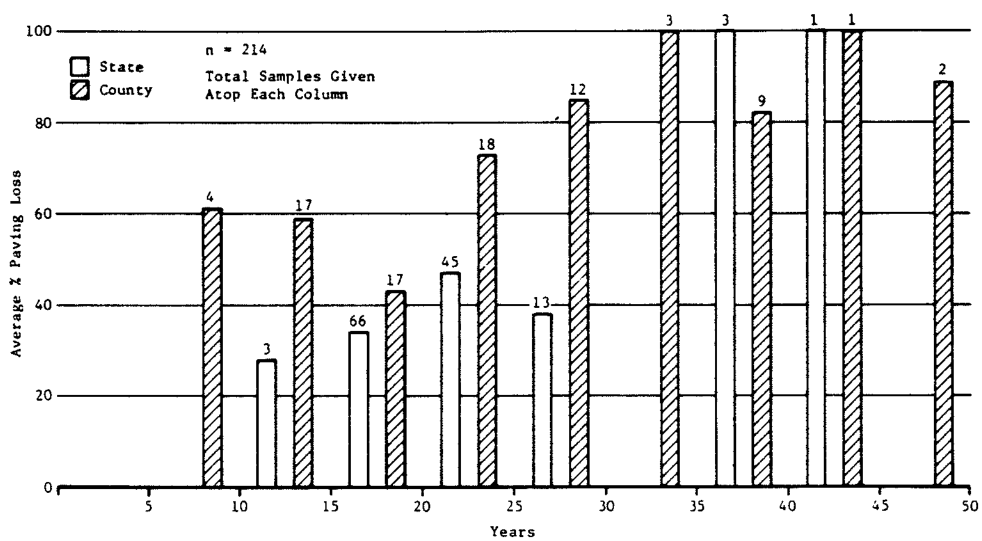

FIGURE 9 Average paving loss (system).

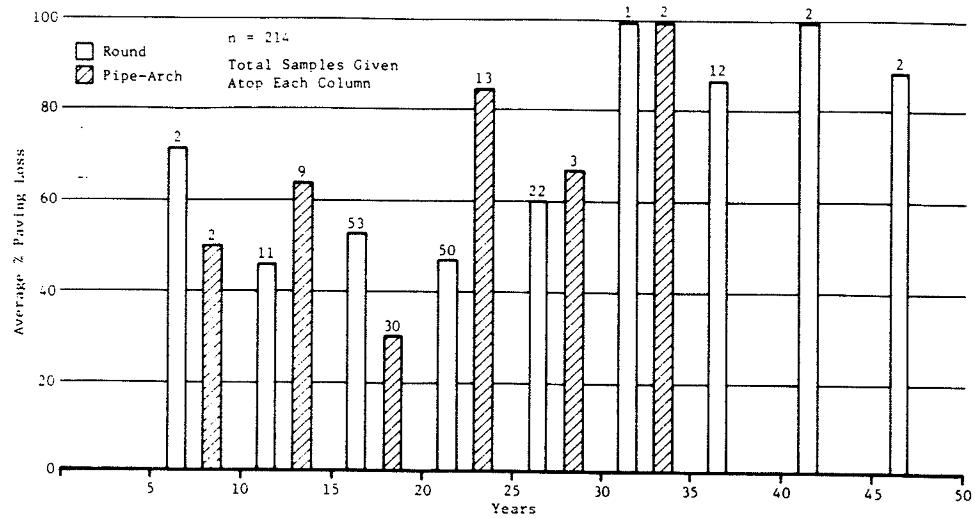

FIGURE 10 Average paving loss (shape).

the combined 6 to 30 age group, the round average loss is 42 percent for 138 pipes and the pipe-arch is 59 percent for 57 pipes. These differences are similar to system differences because state pipes are generally round and about half the county pipes are pipe-arch.

System/Shape

To determine if the differences are caused by system or shape, further analysis was completed. Figure 11 shows the pipe for each age group to 30 years in four categories: state round, state pipe-arch, county round, and county pipe-arch. The numbers of pipes and average percentage losses for the four categories are given in Table 3. As can be noted, state pipes tend to have lower losses than county pipes and round pipes have lower losses than pipe-arches.

Other Variables

Other variables recorded were diameter, pipe slope, inlet slope, culvert use (side ditch or stream), and bedload. An attempt was made to relate all of these variables to paving loss, but no significant trends were found for any of them.

Paving Life

The goal of this study was to determine a paving life that, when added to the life of uncoated CSP, would yield a total life of coated-and-paved CSP. As previously mentioned, New York now has two zones of annual metal loss for uncoated CSP--northern (2 mils) and southern (4 mils). These metal-loss rates are for 90 percent of the pipes; there is a 10 percent probability of these rates being exceeded. This metal loss begins when the paving is removed.

To determine paving life, a percentage of loss that could safely be allowed had to be established. For design purposes, two assumptions have been used in New York. First, paving fails when 50 percent of its length has been removed. Second, from this point on, a metal-loss rate is applied to the pipe as though no paving were available for protection. Over the years, paving loss has been visually and in-

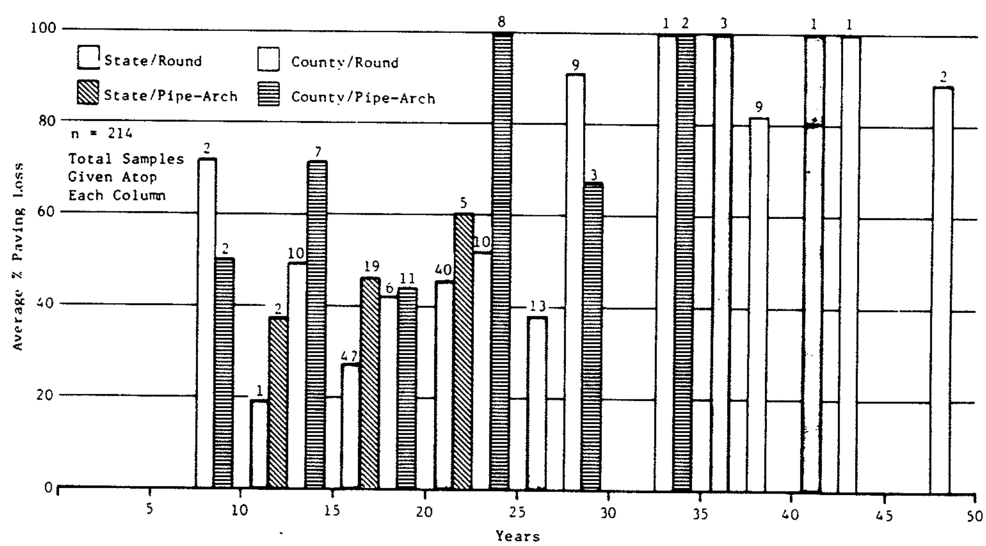

FIGURE 11 Average paving loss (system and shape).

TABLE 3 System and Shape to 30 Years

	Total	Average Loss (%)
State	127	39
County	68	64
Round	138	42
Pipe-arch	57	59
State system		
Round	101	36
Pipe-arch	26	48
County system		
Round	37	60
Pipe-arch	31	67

formally surveyed. From these surveys it was concluded that paving failure occurs in about 25 years. This study was undertaken for better quantification of time to failure.

Referring to Figure 8, it can be seen that the 6 to 10 and 11 to 15 age groups have average losses greater than 50 percent. The 16 to 20 age group has losses less than 50 percent, whereas the next two groups have increasing losses. At 31 years and older the losses are almost all 100 percent. To summarize, the following observations can be made from this figure:

1. The 16 to 20 age group has much lower losses than the adjacent groups (and the greatest number of pipes);
2. The 6 to 10 and 11 to 15 age groups have higher losses;
3. The 16 to 20, 21 to 25, and 25 to 30 age groups have increasing losses; and
4. Beyond 30 years 100 percent loss can be assumed.

It is interesting to note the low average losses in the 16 to 20 age group relative to younger pipes. The reason for this is unclear. With the 6 to 10 group containing only 4 samples, their losses may not reflect the true mean, but when reviewed together with the 11 to 15 age group (20 samples), the difference is quite large. These data are examined further in Table 4, which gives the number of pipes in each category with paving 100 percent removed, and in Table 5, which gives the cumulative totals of the same data.

In the 6 to 10 and 11 to 15 age groups most (21 of 24) are county pipes. Overall, county pipes have a significantly higher percentage with complete paving loss. When state and county pipes are separated into round and pipe-arch, it is clear that the latter have a larger percentage of complete paving loss. Because of their shape, pipe-arches are more likely to carry flow at or above the flow line, which may account for the high failure rate. Even in the other age groups, pipe-arches have a greater 100 percent loss rate than round pipes.

Several other explanations appear possible for the high losses in the second age group: small sample size, more severe sites, and poor coating conditions resulting in poor adhesion. Perhaps the ultimate coating-and-paving life is as much a function of the care and workmanship of the coater and paver as of conditions in the field. A recent FHWA report (9) indicates that coating procedures and conditions vary widely. Two failure modes may exist for coated-and-paved pipe. One type (material failure, i.e., early failure) may be caused by poor workmanship: poor adhesion, dirty pipe when coated, paving not thick or wide enough, and so forth. This could occur at any time during the life of the pipe, but would cause predominantly early failure. The other type (condition failure, i.e., later failure) may be caused by conditions to which the pipe is subjected in the field: water flow, freeze-thaw, abrasion, and so forth. Pipe age is recorded when it is inspected. Thus if paving is 100 percent removed, this could have occurred the day before or as many years before as the age of the pipe. When young pipes fail early, they stand out dramatically, but older pipes blend in with later failures. This and small sample size may account for the high loss in the 6 to 10 and 11 to 15 age groups.

Because considerable differences appear in paving losses between state and county and round and pipe-arch pipes, it would appear imprudent to designate a single time to failure for all paved pipe in New York. Figure 11 shows the differences in losses for the different groups of pipes. None should be assumed to retain paving beyond 30 years. For design purposes, round state pipes can be assumed to reach failure at about 30 years. A life of about 20 years appears justified for state pipe-arches.

TABLE 4 Paving 100 Percent Removed

Age Group (years)	Total	State System			County System		
		Total	Round	Pipe-Arch	Total	Round	Pipe-Arch
6-10	2-4	-	-	-	2-4	1-2	1-2
11-15	6-20	0-3	0-1	0-2	6-17	1-10	5-7
16-20	15-83	11-66	7-47	4-19	4-17	1-6	3-11
21-25	28-63	15-45	12-40	3-5	13-18	5-10	6-8
26-30	9-25	3-13	3-13	-	6-12	4-9	2-3

TABLE 5 Paving 100 Percent Removed, Cumulative

Age Group (years)	Total	State System			County Systems		
		Total	Round	Pipe-Arch	Total	Round	Pipe-Arch
6-10	2-4	-	-	-	2-4	1-2	1-2
6-15	8-24	0-3	0-1	0-2	8-21	2-12	6-9
6-20	23-107	11-69	7-48	4-21	12-38	3-18	9-20
6-25	51-170	26-114	19-88	7-26	25-56	8-28	17-28
6-30	60-195	29-127	22-101	7-26	31-68	12-37	19-31

SUMMARY

In this paper a method of inspecting coated-and-paved CSP, measurements of the amount of coating and paving remaining, and the results of an extensive survey conducted in New York have been described. The following are pertinent findings:

1. Paving lasts longer on round pipes than pipe-arches;
2. Paving lasts longer on state pipes than on county pipes;
3. Beyond 30 years paving is ineffective in protecting CSP in all categories;
4. Paving adds 30 years of life to round pipes on the state system; and
5. Paving adds at least 20 years of life to pipe-arches on the state system.

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