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Metal-Loss Rates of Uncoated Steel and Aluminum Culverts in New York

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ABSTRACT

In this paper a laboratory evaluation is described of three techniques to determine metal loss on 1-in. coupons extracted from corrugated metal pipe, a field evaluation of 30 pipes to determine the sample size (number of coupons) and sampling location necessary to characterize metal loss, and a statewide survey of steel and aluminum culverts in New York. It is concluded that a pin micrometer can be used to measure metal loss and that eight coupons extracted randomly along the "worst straight line" of a pipe will provide the accuracy needed for large-scale field surveys. Results of a field survey of 190 galvanized steel culverts and 35 aluminum culverts are presented, and implementation of these results in New York is discussed.

In 1964 New York State began a study of the durability of corrugated metal pipe culverts. The ultimate objective was to provide designers with reliable data on corrosion and abrasion rates of corrugated aluminum and galvanized steel culverts under environmental conditions encountered in the state.

Initial findings were reported in 1967 (1). In that paper metal loss for 111 uncoated galvanized steel culverts was estimated. The values were obtained by striking the pipe with a geologist's pick and then estimating the amount of metal remaining. This method was thought to provide realistic values because early in the investigation a favorable correlation was found between measured thicknesses of 1-in.-diameter cores from 67 culverts and estimates made by soundings with the pick.

These estimates of metal loss were used in conjunction with subsequently developed data to derive a durability design for New York (2). This was based on annual metal losses of 1 mil for diameters up to 48 in. and 2 mils for larger sizes (1 mil = 0.001 in.). In addition, a rating system was designed to determine the need for asphalt coating and paving. The rating system included such factors as surface water corrosiveness, abrasive character of the bedload, and frequency of flow.

Beginning in 1968, a series of 1-in.-diameter cores was taken from many uncoated galvanized steel culverts throughout the state. A single core was taken in each pipe to represent average conditions along the invert or water line, whichever had the greatest apparent deterioration. Results of thickness measurements on these cores indicated that metal-loss rates were considerably higher than the earlier data suggested. This led to concern about the adequacy of the assumptions made in the design procedure.

Several theories have been advanced to account for the discrepancy between the 1965 estimates and the more recent data:

1. In the 1965 survey no cores were taken from the pipes. Metal loss was visually estimated, aided by soundings with a geologist's pick.
2. The original data were collected toward the end of a 5-year drought, which could tend to reduce indicated corrosion rates.
3. Many pipes included in the first survey were young (less than 10 years old).
4. Both sets of data had weaknesses in sample sizes and distribution of samples throughout the state.
5. The methods used in collecting both sets of data to characterize metal-loss rates within each pipe may not have provided reasonable accuracy.
6. The technique of measuring coupons with a pin micrometer may have overestimated metal loss.
7. The 1-in. samples may have been too small for accurate determination of metal loss at a given location within a pipe.
8. Lack of true randomness in selecting pipe

locations and areas within a pipe to examine and sample may have caused inaccurate results.

After many discussions of these theories, it was decided to undertake a new series of tests that would eliminate most if not all of the apparent weaknesses in the prior work. Accordingly, a program was planned to accomplish three goals:

1. To establish a satisfactory method to determine metal loss from a coupon extracted from a single location within a pipe (Pilot Series I),
2. To determine the number and location of coupons necessary to adequately characterize metal loss within a single pipe (Pilot Series II), and
3. To determine the long-term annual rates of metal loss from corrosion or abrasion or both for galvanized steel and aluminum pipes in New York State.

DEVELOPMENT OF A METHODOLOGY FOR MEASURING METAL-LOSS RATES

Pilot Series I

Pilot Series I was undertaken because of the questionable accuracy of using 1-in.-diameter coupons measured with a pointed micrometer to determine metal loss at a given point in a culvert. Alternative measurement methods were considered, which involved a larger sample specimen, use of a flat micrometer, and actual weight measurements.

Specimen Size

It was suggested that 6 x 6-in. specimens would provide more accurate indications of metal loss at given locations within culverts. Moreover, it was argued that weighing the specimens and comparing them to the weight of an uncorroded specimen of the same size and original gauge thickness would provide an accurate indication of metal loss. Although the reasoning appeared convincing, use of 6 x 6-in. specimens was rejected for several reasons.

Extracting 6 x 6-in. specimens from pipe in the field would be extremely difficult and time-consuming for more than just a few pipes. Also, many pipes had flowing or standing water when inspected. This alone would generally preclude removal by torch-cutting or sawing.

Further problems arise in trimming specimens to exact dimensions so that weights could be compared accurately with standard-size uncorroded specimens. Also, problems could arise in matching the sample specimen corrugations to the standard specimen. If the corrugations did not match, some errors could occur because of varying metal thickness along the corrugations.

In addition, patching the culvert with pipe segments would be cumbersome. Many varieties of patch pieces would be needed to match pipe corrugations, thickness, and degree of curvature. Fastening replacements in the culvert would also be time-consuming and difficult. This is especially important because it was thought from the beginning of this work that up to 30 sample specimens would be needed for adequate characterization of metal loss in each pipe. Although a larger specimen could potentially provide a more accurate determination at a single point in the pipe, the number of small specimens could be increased to the extent that they provided the needed degree of accuracy when calculating mean metal loss for the entire pipe. This should become more evident in discussions later in this paper.

From these considerations it was concluded that 1-in.-diameter cores would provide adequate information for this work. They are relatively easy to obtain, even when there is some water flowing through a pipe; replacement with rubber stoppers is quick and economical; and given a large enough number, they can provide the needed degree of accuracy.

Flat Micrometers, Pointed Micrometers, and Weight Loss

To conduct this experimental work, a 6-ft length of 36-in.-diameter, 12-gauge corrugated steel pipe was obtained. It had been in service about 20 years, and it was uncorroded along the top (crown) and corroded along the bottom (invert). The pipe was of riveted construction and was made up of three sections (or "cans").

Sixty-six cores were taken along the top of the pipe (uncorroded area). Twenty-two were taken from each section at various locations on the pipe corrugations: three each from both the upstream and downstream faces, eight from the crest, and eight from the valley.

Each 1-in.-diameter core was measured with both a pointed (pin) micrometer and a flat micrometer. Average thicknesses, as measured by the pin micrometer, were consistent among the four locations on the pipe corrugations and from section to section of the pipe. They also compared favorably with the nominal thickness for a 12-gauge pipe--109 mils. On the other hand, average thicknesses, as measured by the flat micrometer, were less consistent. The main discrepancy is between relatively flat areas (upstream and downstream faces) and curved areas (crests and valleys). This effect is expected because the flat micrometer "bridges" the curved surface.

Another group of 24 cores was taken along the culvert invert, diametrically opposed to 24 of the 66 cores from the top of the pipe. Six cores each (two in each pipe section) were taken from the upstream and downstream faces, the crest, and the valley. From these samples, 24 pairs of measurements were made by weight, pin micrometer, and flat micrometer. By comparing measurements at the top of the pipe (uncorroded) with those at the invert (corroded), metal lost to corrosion was estimated. Average loss (expressed as a percentage of uncorroded thickness) was about equal for the weight-loss method (23.6 percent) and pin micrometer (21.8 percent). The loss found by the flat micrometer (12.2 percent) was about half that indicated by the other two methods. In this series of measurements the flat-micrometer method provides inferior results, but in a different way than in the previous series. Here the results are fairly consistent from flat areas (upstream and downstream faces) to curved areas (crests and valleys). However, the bridging effect of the flat micrometer causes a significant difference in results when compared with the weight-loss and pin-micrometer methods.

Because the weight-loss and pin-micrometer methods each appear to provide reasonably consistent results and are in reasonably good agreement, it could be argued that the weight-loss method should be used. It is a more direct measurement because it averages the loss on the entire core. Measurements with a pin micrometer are only a sampling of all possible measurements that could be taken. Weight-loss measurements on cores, however, have distinct disadvantages. First, when extracted from culverts, cores are not necessarily uniform in size. They can be cut at various angles, and thus weights may vary. Also, burrs are left on the core, which must be filed down. Their removal is time-consuming and can also cause variations in weight. Second, to be as accurate as possible, cores would have to be taken in pairs (one at the pipe crown and one at the invert). Measuring by the pin-micrometer method thus appears to be a reasonably accurate and convenient way to estimate metal loss.

Pilot Series II

This series was undertaken to select both sample size (number of cores) and sampling location to characterize metal loss in an individual culvert. Previous estimates were based on either visual examination or on extraction and measurement of a single core. Both methods have shortcomings, and when compared they provide divergent results. To remedy this, large numbers of cores were extracted from many pipe installations in the field to examine the variations that could occur. The pin-micrometer method, just discussed, was used.

Selecting Core Locations

A great deal of thought was given to selection of core locations to provide good estimates of corrosion or abrasion loss or both within a single culvert. In previous work the "worst straight line" throughout the length of the pipe was visually determined. A single core was then extracted from an average point on that line. In virtually all pipes examined this way, the worst straight line was perceived to be either at the invert or along the flow line.

This approach suffers from two drawbacks. First, visual selection of the worst straight line throughout the length of the culvert is a rough approximation at best. However, numerous measurements would have to be made throughout the length of the pipe to select a line that represents the greatest corrosion or abrasion. This appeared to be an impractical approach. Thus visual selection of the worst straight line was retained. Any results obtained in this manner must be considered underestimates of the maximum corrosion occurring within each pipe, because it is unlikely that the worst conditions were sampled. Although the extent of this underestimate was not examined in this study, in the authors' opinion the measurements taken were within about 15 percent of the true values.

The second and perhaps more serious drawback of previous work concerned the selection of a single point to represent the supposed average condition throughout the length of the pipe. This can be remedied by extracting and measuring several cores. Average metal loss can be calculated and used as an estimate of pipe condition. In statistical sampling theory, a sample size of 30 is generally considered the breakpoint between large and small samples. Therefore, for this pilot series, a sample size of about 30 randomly selected cores appeared to be a reasonable starting point.

One further consideration was necessary to select the exact sample size. Because of the corrugations in the pipe, the distribution of corrosion and abrasion losses could vary systematically along the pipe. It is conceivable, for example, that the upstream faces and crests of the corrugations could sustain more metal loss than downstream faces and valleys because of their exposure to abrasives. To examine this possibility, a stratified random-sampling procedure was selected. Each of the four positions on the corrugations were to be equally represented in the sample. To keep the sample size at 30 or more, eight locations were selected from each position--a total of 32 sampling locations per pipe.

Field Sampling

In keeping with the statistical theory just mentioned, 30 field sites were located for study. The worst straight line in each pipe was visually selected, 32 sampling locations were randomly identified, and cores were extracted at each location. Results of measurements on these cores did not indicate a consistent difference in metal-loss rates from location to location within pipes. In a few instances, however, a pattern was observed. In one pipe, for example, metal-loss rates for the upstream faces were all higher than for any other positions on the corrugations. Yet in another pipe metal-loss rates for the valleys were nearly all higher than the other positions.

Although there were no consistent differences among locations within most pipes, it appeared prudent to continue a stratified random sampling procedure for all future determinations of metal loss. For pipes that have relatively uniform losses throughout (i.e., the majority), no harm would be done. For those that have nonuniform losses, a stratified random sampling would have the advantage of providing the best estimate of metal loss, in a statistical as well as practical sense.

As noted earlier, 32 cores were extracted from each pipe to provide a large sample for statistical purposes. From the statistical viewpoint, this is a comfortable sample size, but from a practical viewpoint, this is a large and time-consuming sampling requirement. This is especially true when faced with a large-scale field survey of several hundred pipes. Thus data collected from all pipes in this pilot series were examined to see if smaller numbers of cores could be taken without sacrificing a great deal of accuracy in determining metal loss.

The standard deviations of all 32 metal-loss measurements for each pipe were calculated. Most standard deviations (all but four) fell between 0.2 and 0.9 mils per year. Two were less and two were greater (1.78 and 1.51 mils per year). For purposes of selecting a reasonable sample size, a worst-case value of 2.0 was examined. Using the Central Limit Theorem ($\sigma_{\bar{x}} = \sigma/\sqrt{n}$, where $\sigma_{\bar{x}}$ is the standard deviation of the mean, σ is the assumed population standard deviation, and n is the sample size), the variation in the estimated means can be predicted. The values of $\sigma_{\bar{x}}$ and $2\sigma_{\bar{x}}$ for various sample sizes when $\sigma = 2.0$ are as follows:

n	$\sigma_{\bar{x}}$	$2\sigma_{\bar{x}}$
1	2.00	4.00
4	1.00	2.00
9	0.67	1.33
16	0.50	1.00
25	0.40	0.80

The values in the column headed $2\sigma_{\bar{x}}$ are the 95 percent confidence level when estimating the mean. If nine cores were measured, for example, it can be stated that the true mean of the pipe would lie within ±1.33 mils per year of the measured mean. As can be noted from this table, estimates of the true mean become more accurate as sample size increases. However, after a relatively few samples, small increases in accuracy require large increases in sample size.

Selecting sample size thus becomes a matter of balancing the cost of measurements against the degree of accuracy desired. Although it is relatively simple to estimate the cost of sampling, it is difficult to place a dollar value on various levels of accuracy. It was previously mentioned that a sample size of 32 cores per pipe appeared excessively costly, but a sample size of 1 can provide poor accuracy. Thus a sample size between 1 and 32 would be appropriate.

To use the stratified sampling technique previously mentioned, the sample size must be a multiple of four in order to get equal representation of the four positions on the corrugations. A review of the data in the table indicates that once the sample size exceeds nine, the decrease in $2\sigma_{\bar{x}}$ becomes relatively small. Thus it was decided that a sample size of eight (the multiple of four closest to nine) would be used for field surveys.

For the example given in this table, this would place $2\sigma_{\bar{x}}$ at 1.41. In other words, if the true standard deviation for a pipe were 2.00, the true mean metal loss would lie within ±1.41 mils per year of the calculated mean (95 percent confidence level). Although this interval may appear somewhat large, two points should be considered. First, a standard deviation of 1.78 is the largest of the 30 cases observed in this pilot series. The second largest was 1.51. This would yield a confidence interval of ±1.06--about 40 percent below the value just indicated. Thus it was reasoned that the vast majority of estimates of metal loss would be within about 0.5 mil per year of the true value. It was generally agreed that this would provide adequate precision.

The second point to consider is the number of pipes to be evaluated in the field survey. It was anticipated that several hundred pipes would be sampled. Because the metal-loss estimate for each individual pipe would be reasonably accurate, overall statewide assessment of metal loss would be extremely accurate. Small errors in the estimated means of individual pipes would be expected to be balanced between overestimates and underestimates.

Considering all this, a stratified random sample of eight cores per pipe appears adequate to characterize metal losses of pipe for a large-scale survey of pipe condition.

MEASURED METAL-LOSS RATES

Selection of Culvert Sites

Before this study New York used a durability design for galvanized steel culverts based, in part, on a surface-water corrosiveness rating (2). Five geographical areas in the state were assigned relative-corrosiveness ratings based on such factors as soil type, water hardness, and pH. At the time these areas were identified, they were in reasonable agreement with estimated metal-loss rates established in the 1960s. As more data were collected, however, the suitability of using these areas was questioned. Thus an attempt was made to locate enough culvert sites in each area so that their relative corrosiveness could be established.

Initial studies of aluminum culverts indicated that little if any metal loss was occurring. Therefore distribution of sites among the same geographical areas as galvanized steel did not appear critical. This was fortunate because the state has a much smaller population of aluminum culverts.

Originally, it was anticipated that most installations would be at least 20 years old. In reality, this goal could not be met. One problem is that New York had previously specified asphalt coating or asphalt coating and paving on prefabricated pipe. Also, some of the geographical areas were relatively small and contained few highways. In addition, over the years many culverts had been replaced because of washouts and other factors.

All state projects constructed using galvanized steel since the 1920s were reviewed. Because they did not yield the desired number of sites, town and county officials were contacted in an effort to locate more. Where adequate records existed, several more sites were added to the program. During the actual field work many sites had to be eliminated. Some culverts had been replaced by other materials, some were totally inaccessible because of debris or extremely high water levels, and some were concrete or asphalt coated and paved. For these and numerous other reasons, the final number of galvanized steel culverts examined was 190. Although this fell short of the original goal, there were enough to characterize metal-loss rates within the state.

Thirty-five suitable aluminum sites were tested, mostly on town and county projects. Although this number is relatively low, it represents virtually all sites available for inspection.

Data Collection

Field Work

A table of random numbers was used to select the eight sampling locations throughout the length of the culvert along a straight line of "worst corrosion." If a randomly selected location was at a point where the pipe was perforated, then a metal-loss equivalent to the original metal thickness was recorded.

In addition to the eight samples taken along the invert of the culvert, another core was taken in an uncorroded area at the top of the pipe to determine the original metal thickness. It was also used to obtained a rough indication of the condition of the soil side of the pipe.

Some sites had two or more culverts side-by-side in a stream channel. In those instances only the one that appeared to carry the most water or carried water most often was sampled.

Earlier New York studies failed to detect a direct relationship among a number of environmental factors and metal loss. One last attempt was made in this study to establish a relationship between pipe gradient and metal-loss rate. In each culvert the gradient was measured by use of a string-and-line level.

Laboratory Work

All cores extracted from culverts in the field were brought to the laboratory for cleaning and measuring. After cleaning, 10 measurements were made on each core by two persons. The results were combined to determine average thickness.

Metal-Loss Rates

After calculating the average thickness of each invert core, metal loss was determined by subtracting that value from the thickness of the core taken at the crown of the culvert. Thickness of the crown sample was preferred over a theoretical gauge thickness, unless the crown sample exhibited corrosion loss. Average annual metal loss for each culvert was obtained by dividing the average metal loss for all eight cores by the age of the pipe.

Data Analysis

Steel Culverts

After metal-loss rates were determined, the first step in data analysis consisted of plotting all these rates on a large state map. Each value was plotted according to its geographic location. The plotted points were color-coded to indicate the relative severity of metal-loss rates.

It was anticipated that the map would be overlaid with the five areas of relative corrosiveness discussed earlier under Selection of Culvert Sites. Before that was done, however, a decided trend was observed in the data. It was obvious to all engineers who viewed the map that metal-loss rates in the southern portion of the state were generally much higher than in the northern portion.

Several engineers were asked to draw a line separating the state into two zones representing relatively high and relatively low metal-loss rates. All lines drawn were quite close together, and a composite line was then created.

Figure 1 shows all metal-loss rates plotted on a state map. Each value is designated by a symbol indicating its metal-loss range. Culverts that had perforations are also marked, and the composite line is shown. The northern portion of the state above the line is designated Zone 1 and the southern portion Zone 2.

Next the two zones were compared to the original five areas of relative corrosiveness. Figure 2 shows these areas along with the composite line dividing the state into two zones. As can be seen, all of Area A (least corrosive), virtually all of Area B, and nearly all of Area C are in Zone 1. On the other hand, Zone 2 is almost exclusively composed of Areas D and E (most corrosive). In this sense, the old and new divisions of the state are in general agreement. However, one major discrepancy exists. A large portion of Zone 1 contains Areas D and E, which were previously assumed to be most corrosive.

Earlier work suggested that structural-plate culverts tended to have lower metal-loss rates than prefabricated pipes. This was reexamined with the current data. In both zones structural-plate pipes have less metal loss than prefabricated pipes, but the differences are not particularly large. Therefore it was decided that all data for each zone could be combined to characterize metal-loss rates.

Further review of the data in the two zones reveals considerable differences in the number of culverts that have perforations or complete metal removal. The most severe losses occurred in Zone 2. Of the 75 culverts in that zone, nearly half (34) had perforations at the flow line or invert. By contrast, only 6 of 115 culverts in Zone 1 exhibited such metal loss.

The gradient of each culvert was measured in an attempt to determine if a relationship could be established between grade and metal-loss rate. Although common sense would indicate that such a relationship should exist, in fact it did not. Of all pipes examined, however, only 16 had gradients greater than 4 percent. Nevertheless, average metal losses for all gradients up to 12 percent remained essentially the same. In addition to the fact that most gradients were relatively low, other environmental factors appeared to play a more important role.

The ninth core taken at the crown of the pipe was used to determine original metal thickness and also a rough indication of the condition of the soil side of the pipe. In nearly all cases the galvanizing was intact. In the remainder some galvanizing loss and light rusting was evident. No heavy pitting was observed. This confirms previous observations that suggested that soil-side corrosion was not a significant problem in galvanized steel culverts in New York.

Aluminum Culverts

Although it was anticipated that aluminum culverts would exhibit low metal-loss rates, the same sampling plan was used: eight cores randomly selected from the invert or flow line of each pipe, two each from the four positions on the corrugations, plus a single core from the crown. As expected, metal-loss

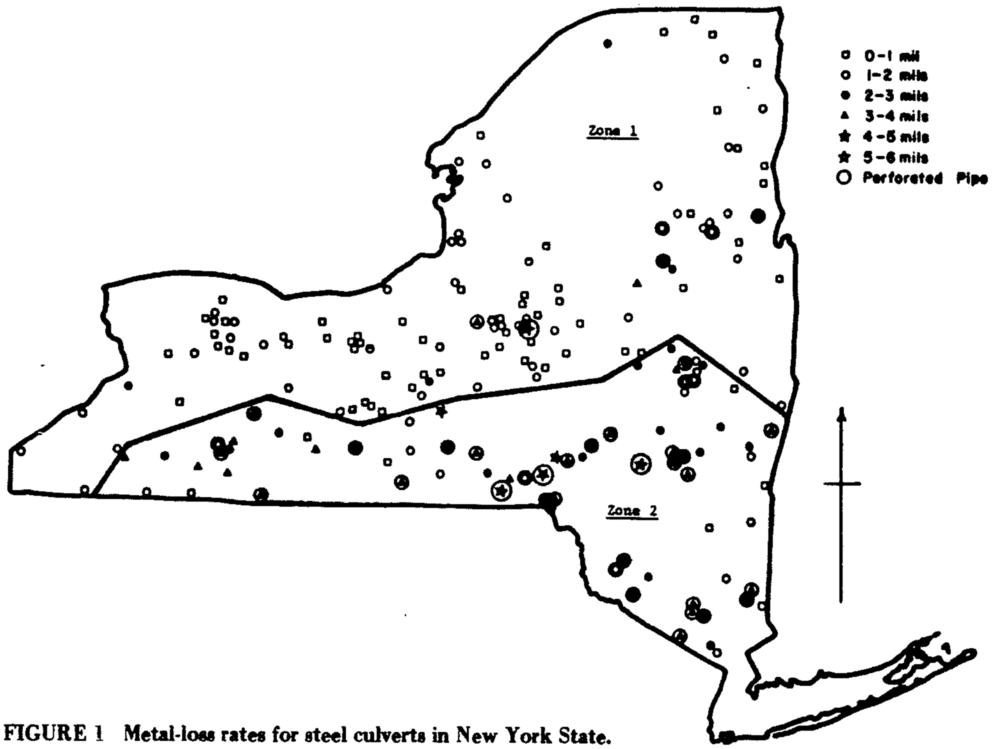

FIGURE 1 Metal-loss rates for steel culverts in New York State.

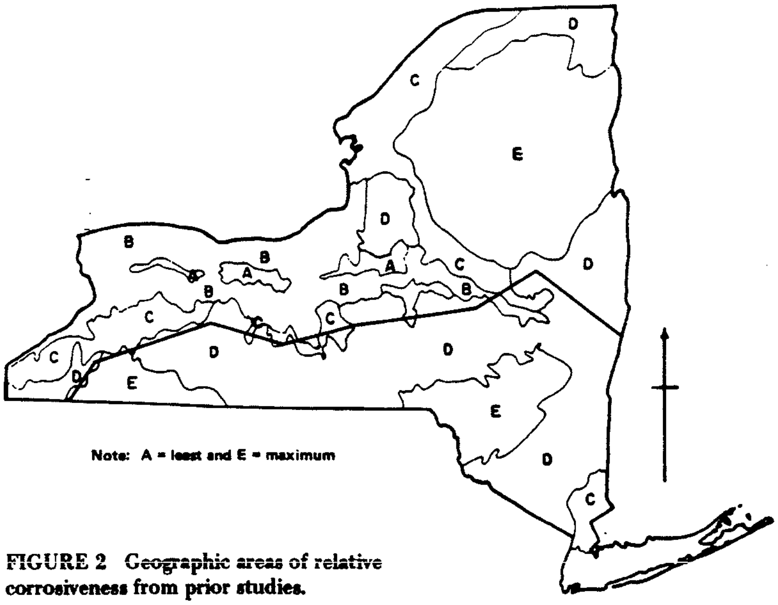

FIGURE 2 Geographic areas of relative corrosiveness from prior studies.

rates were low. None of the culverts had a loss more than 1 mil per year. Although the aluminum culverts are well distributed in the two zones identified for steel pipe, their metal-loss rates are equally low in both.

Figure 3 summarizes the metal-loss results for steel (separated by zone) and aluminum culverts in New York.

Implementation of Results

Steel Culverts

Based on these results, several suggestions were made for New York State. It was pointed out that for steel pipe, no special durability design is necessary to protect the outside of the pipe or the inside above the flow line. However, it is important to provide enough metal thickness at or below the flow line to account for metal lost during the design life of the pipe. To accomplish this, two factors need to be established:

1. The expected metal-loss rate for a particular installation, and
2. The point at which it should be replaced or repaired.

Metal-loss rates were established on a probabilistic basis for the two geographic zones described. For Zone 1, a metal-loss rate of 2 mils per year was selected. About 90 percent of all steel culverts will have losses equal to or less than this amount. For Zone 2, a value of 4 mils per year was chosen; again, about 90 percent of the culverts in that zone will have losses no greater than that amount.

Establishing the point at which a culvert reaches the end of its useful life is more difficult. It could be argued that the safest point is when the structural safety factor of the installation reaches

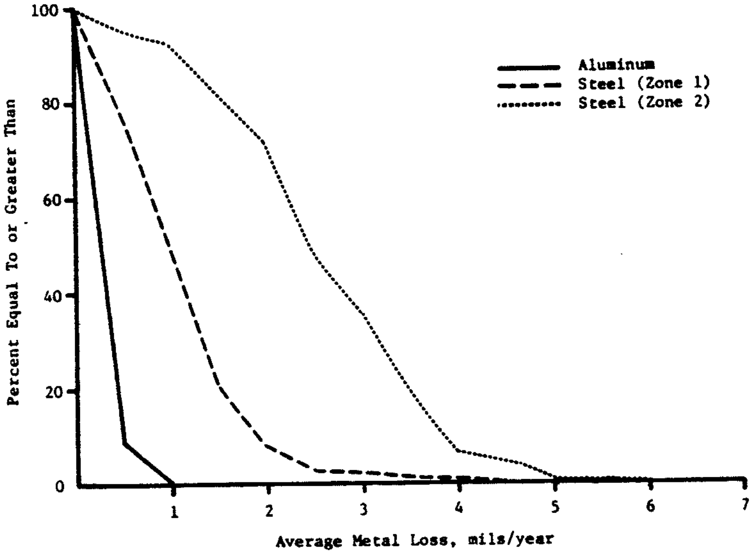

FIGURE 3 Distribution of average metal loss for uncoated aluminum and steel culverts.

a value of 1.0. In reality, this point can only be estimated rather crudely. Another argument could be made that many culverts with inverts completely removed are still in service. From a structural standpoint, however, those installations are at best unstable.

For design purposes, New York has established a theoretical end point. It is when the culvert invert or flow line would be completely removed if the design metal loss (2 or 4 mils per year) occurred uniformly throughout the length of the culvert.

The following example will demonstrate the design procedure. Assume that hydraulically and structurally an installation in Zone 1 requires a 48-in.-diameter, 14-gauge steel pipe. Using a metal-loss rate of 2 mils per year for a design life of 50 years would require a minimum 100-mil metal thickness. Because 14-gauge pipe has a nominal 79-mil thickness, it does not satisfy the durability requirement. Therefore, either a 12-gauge pipe (109 mils) must be used or a protective coating of suitable durability must be applied to the 14-gauge pipe.

Aluminum Culverts

The design concepts applied to steel culverts also apply to aluminum culverts; that is, a design metal-loss rate and an end point in the life of the culvert should be established. Based on the results of this study, a metal-loss rate of 0.5 mils per year was selected. This value would be exceeded about 10 percent of the time. The same theoretical end point can be applied to aluminum as steel; that is, the point at which the invert or flow line would be completely removed if the design metal loss (0.5 mil) occurred uniformly throughout the length of the culvert.

In practice, application of these criteria to aluminum culverts is quite simple. Based on the maximum 70-year design life, only a 35-mil metal thickness would be required. This is substantially below the minimum thickness necessary for structural integrity, and thus no special durability considerations are required.

ACKNOWLEDGMENT

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[Authors' note: Readers interested in a more detailed account of this research should request Research Report 115, "Metal-Loss Rates of Uncoated Steel and Aluminum Culverts in New York," available without charge from the Engineering Research and Development Bureau, New York State Department of Transportation, Albany, N.Y. 12232.]

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Bacterial Corrosion of Steel Culvert Pipe in Wisconsin

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ABSTRACT

An ongoing project to investigate culvert corrosion in Wisconsin has indicated that anaerobic sulfate-reducing bacteria were a contributing factor in the corrosion of galvanized steel culvert pipe at 31 percent of the culvert sites examined since 1972. Two corrosion products and two environments of corrosion are characteristic of bacterial corrosion. One association is oxidation scale, which is related to bacteria active in organic, poorly drained soils of near-neutral pH. The other is nodular oxidation, which is related to bacterial colonies on the pipe surface associated with a water source of nutrients and characterized by local perforations of the invert, particularly along the flow lines. In this paper field tests are discussed and a description of the occurrences is given.

A continuing program to investigate culvert corrosion has been in effect in Wisconsin since 1965 and has involved the examination of approximately 500 culvert sites. This program was initiated by using equipment and procedures described in California Test Method 643-B (1,2). This is a system for predicting culvert pipe corrosion rates based on pH and electrical resistivity values of soil and water at a culvert site. Higher corrosion rates are associated with lower values of pH and resistivity. Predicted times to perforation of culvert pipe afforded by the