Durability of Drainage Structures

KENNETH M. JACOBS

ABSTRACT

The study evaluated various culvert materials and coatings for durability. The primary emphasis of the evaluation was on corrosion of metal pipes and loss of aggregates in reinforced-concrete pipes. The design of culvert installations in Maine are primarily on relatively flat grades; thus erosion and abrasion are generally not a problem. Culverts installed by the Construction and Maintenance divisions of the Maine Department of Transportation throughout the years and experimentally installed culverts were evaluated for durability. Those culverts installed by the Construction and Maintenance divisions were asbestos-bonded bituminous-coated corrugated metal pipes, asbestos-cement pipes, clad-aluminum alloy culvert pipes, aluminum-alloy structural plate pipes, bituminous coated with paved invert corrugated metal pipes and corrugated metal pipes (steel), and reinforced-concrete pipes. Those culverts installed experimentally were aluminum-coated corrugated metal pipes, aluminum-zinc-coated corrugated metal pipes, polymeric-coated corrugated metal pipes, and post-epoxy-coated corrugated metal pipes. Estimated service life was determined for corrugated metal pipe (steel), bituminous coated with paved invert corrugated metal pipe (steel), reinforced-concrete pipe, and aluminum-alloy corrugated metal pipe. For those culvert pipes installed experimentally, no estimated service life was determined, but the conditions of the pipes were noted.

The advent of higher geometric design standards for highways resulted, in many cases, in higher fills over longer drainage structures. Thus the service life of drainage structures has become more critical because if the drainage structure is to be replaced, it may well become a major maintenance operation. It was believed that if information could be developed for estimating the service lives for the various materials used in the manufacture of culverts, it would be beneficial to the Design Division of the Maine Department of Transportation (MeDOT).

Service life, or durability, is an important consideration because the MeDOT Maintenance Division spends approximately $500,000 to $600,000 each year for the replacement of culverts. This amount does not include installation costs, which would double this amount. If the estimated service life for a certain culvert material was known, a risk or probability factor could be assigned for a particular drainage site, which should result in future savings.

The environment in Maine has proved harsh for drainage structures. The fact that the state has relatively high annual rainfall, areas where the effluent has a low pH, and many tidal sites has resulted in the rapid deterioration of certain types of drainage structures. It was believed that a limited determination of the conditions that prove to be most detrimental to certain culvert materials could be made. Therefore, it was decided to obtain data on various culvert materials to improve service life.

SCOPE OF PROJECT

The main objective of the study was to determine the service life of the more commonly used culvert materials in Maine. The study consisted of evaluating culverts that had been installed by the department's construction and maintenance programs. The culvert materials studied included bituminous coated with paved invert corrugated metal pipes, corrugated metal pipes, clad-aluminum alloy pipes, reinforced-concrete pipes, plus a small number of asbestos-cement pipes and asbestos-bonded bituminous-coated corrugated metal pipes. This study also included experimental culverts that have been installed recently (2 to 10 years).

METHODOLOGY

The variables that effect the service life (durability) of drainage pipe are quite complex. A partial list of variables that contribute to corrosion and abrasion problems are water velocities, oxygen concentrations, water temperature, pH of soils and water, electrical resistivity of soil and water, and bedload. To obtain an accurate estimate of service life, a number of measurements of these and other variables are required for an extended period of time. This not being practical or possible for all sites, one approach to the problem of estimating service life for drainage structures with somewhat similar environmental conditions was to consider corrosion and abrasion as a frequency distribution resulting from a totality of those variables. MeDOT has designed nearly all culvert installations for a relatively flat slope; thus abrasion was generally not a problem. Also, the department, as a standard practice, has backfilled culverts with granular material; thus nearly all resistivity readings were found to be greater than 10,000 ohm-cm.

To achieve representative sampling, an attempt was made to obtain geographic dispersal in the belief this would provide a better statewide average of environmental conditions that affect drainage structures. The parameters that could be measured were pH of water, resistivity of soil, stream flow (frequency), and water velocity where applicable (high velocity stream). The two conditions that were obtained as standard procedure were pH of the water (when possible) and the resistivity of the soil for metal culvert sites. Resistivity readings were not obtained for the reinforced-concrete pipe and asbestos-cement pipe because these pipes, generally speaking, are nonconductors. All field soil resistivity measurements were obtained with a Vibroground single probe, 97-Hz resistivity meter. With this resistivity meter accurate information could be obtained quickly with little interference from stray ground currents or overhead 60-Hz powerline interference.

Drainage Structures Installed by Construction and Maintenance Programs

The study was divided into two sections; the first section considered culvert pipes that have been installed by the department's construction and maintenance programs for a number of years. The second section dealt with experimental culvert pipes that have been installed for evaluation.

A facsimile of the forms used by the inspection team is shown in Figure 1. The six-class numerical condition rating shown in Figure 1 is further described in Figure 2.

Asbestos-Bonded Bituminous-Coated Corrugated Metal Pipe

A small number of asbestos-bonded bituminous-coated corrugated metal pipes located in a saltwater environment were evaluated. Of these six culverts, four were in the Portland area, three of which were installed in 1948 and one in 1969. Two other saltwater installations were evaluated, one at Owls Head on Ash Point (installed in 1939) and one in Damariscotta (installed in 1962).

Asbestos-Cement Culvert Pipe

The procedures used in sampling the asbestos-cement pipe (ACP) were similar to those used when sampling the reinforced-concrete pipes (see Figure 2). The number of ACPs used by the department was relatively small. The oldest installations were 18 years old.

Clad-Aluminum Alloy Culvert Pipe

The clad-aluminum alloy pipe (CAAP) has been used for almost 20 years in Maine. The sampling proce-

Revised

MAINE DEPARTMENT OF TRANSPORTATION

Project No.________Town________Date Inspected__________Yr. 19______

Approx. Location________________Date Installed__________Yr. 19______

Type of Structure: Rigid Pipe ☐ Flexible Pipe ☐ Age (In Years)________

RIGID STRUCTURES

R.C. Pipe☐, R.C. Pipe Arch☐, Asbestos Cement Pipe☐, Class____________

Diameter_____inches, Span_____inches, Rise_____inches, Length________Ft.

Type of joint: Mortar☐, Plastic☐, Condition Joint: Top___Bottom______

End Design: Head Wall Yes ☐, No ☐

Condition of Rigid Pipe (check most appropriate one)

Cracked: Top Yes☐, No☐, Width____, Bottom Yes☐, No☐, Width________

☐ 0 Original condition

☐ 1 Discoloration, slight spalling of mortar, no softening

☐ 2 Slight spalling of smaller aggregates

☐ 3 Moderate spalling of aggregate, loss of mortar and aggregate, minor amounts of softening

☐ 4 Extensive spalling of concrete and reinforcing steel exposed, a few small holes in invert, moderate amounts of softening

☐ 5 Invert completely deteriorated

FLEXIBLE STRUCTURES

C.M.P.☐, B.C.C.M.P.☐, Aluminum☐, Spiral C.M.P.☐, Spiral B.C.C.M.P.☐,

Gage_______Type of Structure: Pipe☐, Pipe Arch☐, Structural Plate☐,

Diameter_____inches, Span_____inches, Rise_____inches, Length____ft.

End Design: Headwall Yes☐, No☐, Apron Yes☐, No☐, Other__________

Condition of Flexible Pipe (check most appropriate one)

☐ 0 Original condition

☐ 1 Superficial rust (no pitting)

☐ 2 Moderate rust (minor pitting in invert)

☐ 3 Fairly heavy rust (moderate pitting in invert)

☐ 4 Heavy rust (deep pitting in invert) and some perforations

☐ 5 Unsound areas, extensive perforations to invert completely deteriorated

B.C.C.M.P.: Coating intact Top 2/3____%; Coating intact Bottom 1/3_______%

Type of Paved Invert: Pad☐, Dipped Process☐, Coated only☐

Percent of Pad ontact________________, Manufacturer________________

ENVIRONMENT AT CULVERT SITE

Water Conditions: Dry☐, Running water☐, Still water☐, Water depth in culvert_____in.

Stream flow: Intermittent☐, Frequent☐, Continuous☐, Water Temperature__

Stream bed: Ledge☐, Gravel☐, Sandy☐, Clay☐, Rock Laden☐, Veg.☐

Culvert self cleaning☐, Silted☐, Depth of silting____inches, Erosive☐, Slope of pipe_____%, Velocity (if applicable)______________fps

Water runoff from: Cultivated Land☐, Pasture Land☐, Woodland☐, Wooded Swamp☐, Swamp☐, Sewerage☐, Saltwater☐, Other (describe)______________________

Water Sample No.________at inlet, Water Sample No.________at Outlet

pH inlet____________, pH outlet____________________

Backfill Soils: Resistivity Ohm-Cm________, Fill height over pipe______ft.

Soil Type: Granular☐, Silt or clayey gravel & sand☐, Silty soils☐, Clayey Soil☐

General Comments:____

FIGURE 1 Form for evaluating culverts.

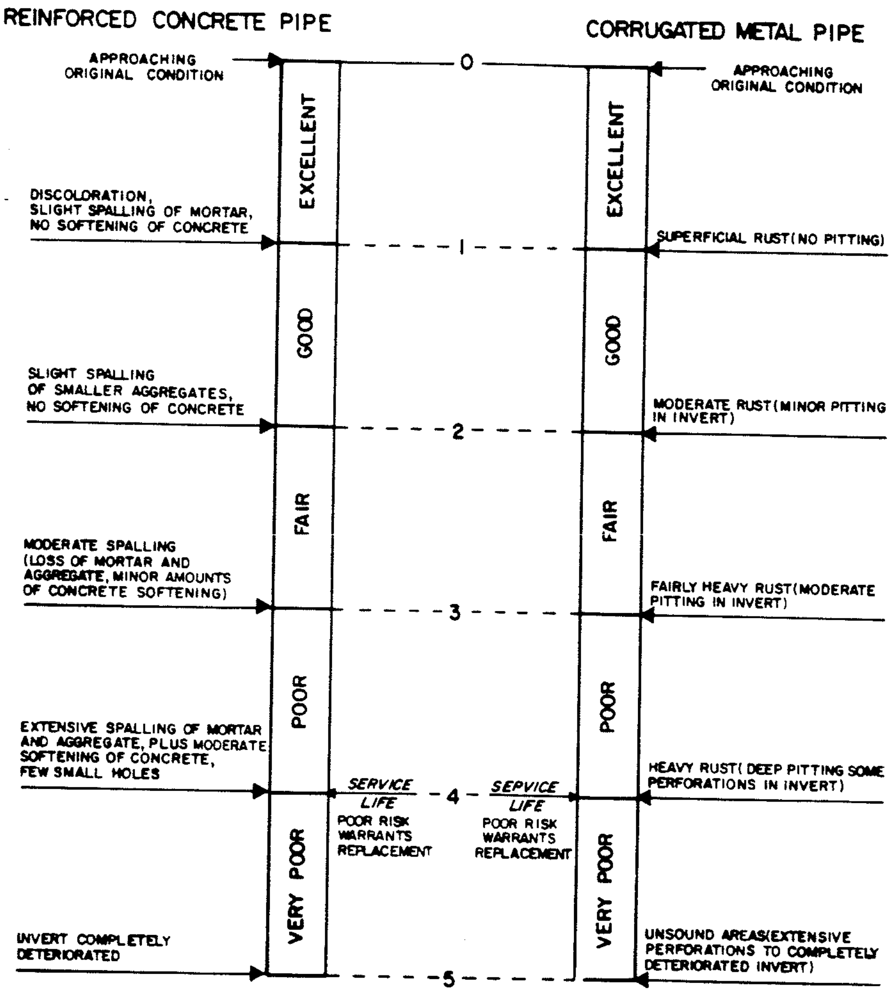

FIGURE 2 Culvert pipe evaluation scale.

dures were similar to those used when sampling galvanized steel pipe (see Figures 1 and 2).

CAAPs in tidal water were evaluated for durability in an environment that has resulted in serious corrosion problems for corrugated metal pipe (steel pipe).

Aluminum Alloy Structural Plates and Culvert Pipes

Aluminum alloy structural plates were rated for condition as were the aluminum alloy culvert pipes, but the sample size was quite small and an analysis for expected service life was not completed. All the aluminum structural plates were in a tidal water environment, with three of the structures being subjected to daily tides. These three structures were located in Robbinston (15 years old), North Lubec (12 years old), and Lamoine (3 years old). In Perry an 11-year-old structural plate that was generally in fresh waters was subjected to saltwater only during extremely high tides.

Bituminous Coated with Paved Invert Corrugated Metal Pipe and Corrugated Metal Pipe (Steel)

For the corrugated metal culverts, zinc coated and bituminous coated with paved inverts [corrugated metal pipe (CMP) and bituminous-coated corrugated metal pipe (BCCMP)], it was difficult to reliably measure the wall thicknesses of the CMPs because of the variance in thickness of the zinc coating and the base steel. Also, difficulty was encountered in obtaining representative measurements of those portions of the culvert that had partially deteriorated. Therefore, to determine the amount of deterioration, several measurements were obtained and averaged.

The original gauge thickness was determined by micrometer measurements along with thickness for the deteriorated portion of the pipe to establish the rate of deterioration per year. This variation required the evaluation of a large number of samples for developing a frequency distribution of an average yearly loss of metal. This large variation also suggested that environmental conditions varied considerably among the sites sampled.

The composition of the galvanized sheet from which corrugated steel was produced may have changed somewhat in the samples taken from culverts installed before 1940, which had copper contents of less than 0.05 percent, and those after 1950, which had copper contents greater than 0.20 percent.

At some of the preselected culvert sites the culvert pipes had to be replaced since the 1972 inspection; in those instances the 1972 data were used.

Reinforced-Concrete Pipes

The rating system established for reinforced-concrete pipe (RCP) was concerned primarily with deterioration, spalling, and softening of the concrete in the area of the invert. Softening was defined as concrete that could be easily dislodged with a small hammer. To evaluate the condition of the structure and provide a method for determining an estimated service life, a six-class rating system was developed. Although the depth of spalling could be measured, the extent of concrete softening was difficult to be determined; thus the rating was considered somewhat subjective (see Figure 2). Unless the structure was in nearly original condition or the invert was completely deteriorated, there was always the difficulty of assigning the most appropriate condition rating for the culvert. When the inspector evaluated the structure, it was rated for the amount of deterioration on the scale of 0 through 5 (Figure 2).

Experimentally Installed Drainage Structures

The department has installed experimentally a number of culvert pipes that have been manufactured by using different materials and coatings. These experimental installations were inspected and evaluated to determine how well the various culverts were performing.

Aluminum-Coated Corrugated Metal Pipe

The aluminum-coated corrugated metal pipe (ALCCMP), Aluminized II, was installed at four locations within the state in addition to those installed by the Maintenance Division. These culverts were installed in 1978 and 1979; therefore, it was difficult to determine their performance.

Aluminum-Zinc-Coated Corrugated Metal Pipe

The department installed five aluminum-zinc-coated corrugated metal pipes (ALZCCMPs) in 1973. These culverts were evaluated in 1978 and 1981-1982, as were zinc-coated pipes that were also installed at most sites, either adjacent or in tandem with the ALZCCMP.

Polymeric-Coated Corrugated Metal Pipe

One polymeric-coated pipe was installed in 1972. This was a 48-in. culvert with a polymeric coating on the effluent side of the pipe. This culvert was evaluated after 5 and 10 years service.

Epoxy-Coated Corrugated Metal Pipe

The department has installed two epoxy-coated corrugated metal pipes: one in tidal water and the other in inland waters. These culverts have been in service for only 2 years; thus it was not feasible to make any projection on their performance. These two culverts were rated as 0 or nearly original condition after 2 years of service.

ANALYSIS OF DATA

The data were collected with the consideration that statistical analyses could be completed, and from them it would be possible to interpolate or extrapolate approximate service lives for drainage structures in Maine. Service life was defined as a culvert rated as condition 4 (see Figure 2). Although condition 4 does not necessarily constitute failure, it does represent a poor risk and warrants replacement.

The problem that was evident from the conception of the study was the number of parameters that could not be measured directly. Thus, as in the case of condition, numerical values were assigned for each rating. Regression analyses were used to determine the influence of the independent variables (resistivity, pH, stream flow, and age) on the dependent variable condition. Simple linear regression was used to express the relationship between culvert condition and culvert age, which provided an approximate service life for the particular type of culvert being analyzed. This procedure was used for corrugated metal, corrugated metal bituminous coated with paved invert, corrugated aluminum alloy, and reinforced-concrete pipes. The average metal loss per year was also used to estimate the service life of the culverts.

As a measure of how well the regression fits the data, a ratio of the reduction sum of squares to the total sum of squares or a coefficient of determination was computed. This was symbolized by r^2. Confidence limits of 90 percent were computed for BCCMP, CMP, and RCP to indicate the true mean of Y for a given X, unless a one-in-ten chance has occurred.

Drainage Structures Installed by Construction and Maintenance Programs

The culvert pipes installed by the department's construction and maintenance programs were in large numbers and a wide range of age. This provided a large statistical base from which an estimated service life could be determined for three of the more commonly used materials.

Asbestos-Bonded Bituminous-Coated Corrugated Metal Pipe

There were six asbestos-bonded BCCMPs evaluated, all of which were in tidal water. The service life for this type of culvert in this type of environment appears to be approximately 35 to 40 years.

Asbestos-Cement Culvert Pipe

A relatively small number of ACPs were evaluated, and all the pipes appeared to be in excellent condition (i.e., rated either 0 or 1). The only apparent problem found when inspecting ACPs was that roadside mowing had in many instances damaged the inlets and outlets of these pipes.

Clad-Aluminum Alloy Culvert Pipe

An evaluation was completed on 44 aluminum culverts. Cores or field measurements were obtained on approximately 85 percent of these pipes. The average metal loss was found to be 0.0002 in., with a standard deviation of 0.0004 in. The average metal loss was somewhat higher than the results found in 1976 when the mean was 0.00014 in., with a standard deviation of 0.0001 in. (1). If the results from these two evaluations are correct, it appears that the corrosion rate may be accelerating slightly with age. Based on these later and more conservative results, the time to perforation would still be more than 100 years for 16-gauge culvert pipe.

Exceptionally good durability was found for the aluminum culvert pipe for both freshwater and saltwater installations. It should be noted that the pH readings were all in what would be considered the normal range, and the resistivity values were greater than 10,000 ohm-cm. The most serious problem noted was the excessive deflections found at a number of sites. Thus it appears that care should be used when compacting the soils adjacent to aluminum culverts to prevent the development of excessive deflections.

Aluminum Alloy Structural Plate Pipe

The aluminum alloy structural plates were rated for condition as were the aluminum alloy culvert pipes, but the sample size was quite small and an analysis for expected service life was not completed. All the aluminum structural plates that were evaluated were in a tidal water environment, with three of the structures being subjected to tidal water during high tides. These three structures were located in Robbinston (15 years old), North Lubec (12 years old), and Lamoine (3 years old). These structures were rated 2, 1, and 0, respectively. The structures at Robbinston and North Lubec revealed minor pitting, which may have been the result of bedload. Considering the harsh environment of these pipes, they have performed well.

Bituminous Coated with Paved Invert Corrugated Metal Pipes

An evaluation of 103 BCCMPs, ranging in age from 2 to 44 years, was completed. An approximate service life of 40 years was determined based on a sample size of 72 BCCMPs that were 14 gauge. The r^2 for the linear regression was found to be 0.53. The confidence limits for BCCMP are quite wide (see Figure 3). This value (40-year service life) was in close agreement with results of a study by Jacobs (2), which estimated a 42-year service life for 14-gauge BCCMP (see Figure 3).

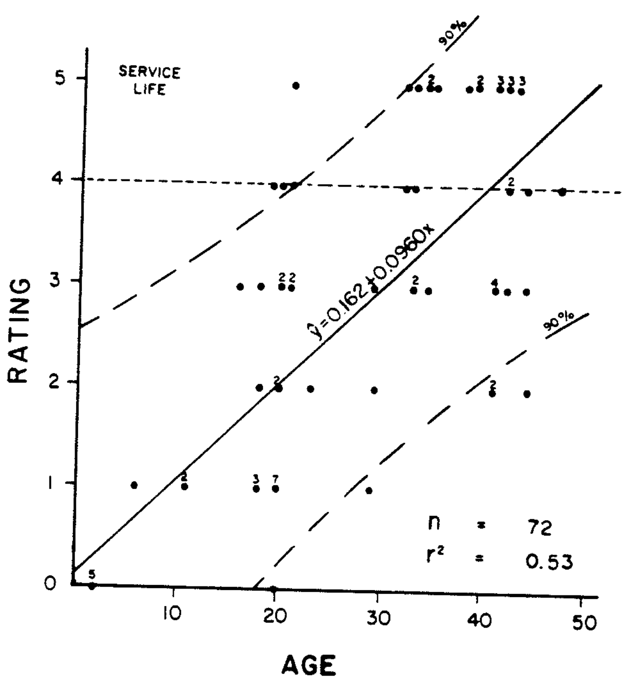

FIGURE 3 Condition versus age for BCCMP, 14 gauge.

If the bituminous paved invert adhered to the corrugated metal pipe, it provided the added service life anticipated. However, in many instances there appeared to be delamination of the paved invert after only a short period, whereas other installations with 20 years or more of service were completely intact. This inconsistency of performance for the paved invert is somewhat reflected in the low r^2 value for the BCCMP. A multiple regression was computed to determine what influence resistivity, pH, stream flow, and age had on the dependent variable condition and to determine if these variables were statistically significant. Resistivity was found not to have a significant effect on condition, whereas pH and age did have a significant effect at the 1 percent level and stream flow was significant at the 5 percent level. The reason resistivity may not have had a significant effect on condition was that resistivity values were generally quite high.

Based on service life values for CMP and BCCMP, it appeared that bituminous coating added approximately 7 to 8 years to the service life, allowing for gauge difference (see Figures 3 and 4).

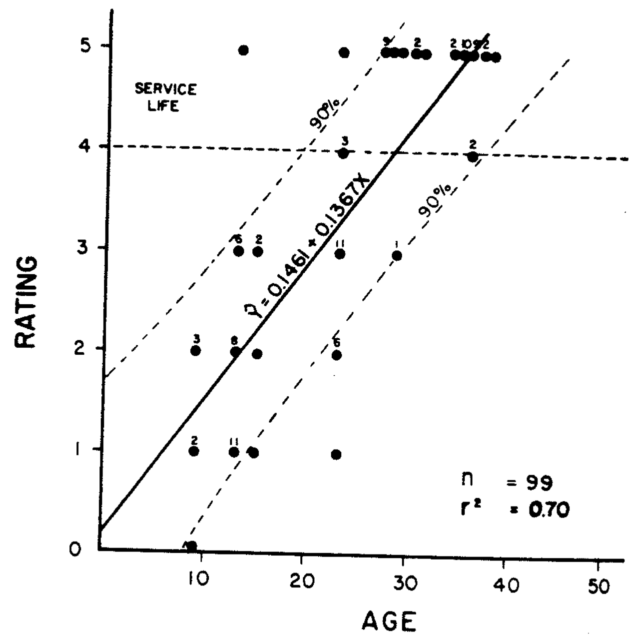

FIGURE 4 Condition versus age for CMP, 16 gauge.

Corrugated Metal Pipe (Steel)

The evaluation of CMP consisted of 99 structures ranging in age from 9 to 45 years. The estimated service life for CMP was found to be approximately 28 years for 16 gauge. The estimated service life was determined from the data by using a weighted value of 0.81 for the 14-gauge culvert pipe and the linear regression computed as shown in Figure 4. For those culverts cored, the average metal loss per year was 0.0021 in., with a standard deviation of 0.0006 in. The linear regression was found to have an r^2 of 0.70. The confidence band for CMP was considerably narrower than for BCCMP (see Figures 3 and 4). Thus the estimated service life by the condition rating was within approximately 7 percent of that for the average metal loss per year (i.e., a 16-gauge pipe had an estimated average service life of 30 years based on an average metal loss of 0.0021 in. per year). The rate of deterioration was somewhat less for the 14-gauge culverts than for 16-gauge culverts. This may be the result of the scale providing protection for a period of time.

The analyses of the multiple regression, as in the BCCMP analysis, indicated that resistivity did not have a significant effect on condition, whereas pH and age did have a significant effect on condition at the 1 percent level. Stream flow had a significant effect on condition at the 5 percent level.

Reinforced Concrete Pipe

The evaluation of 64 RCPs indicated a service life of 65 to 70 years (see Figure 5). The r^2 for the linear regression was found to be 0.53, and it had a wide confidence band, as shown in Figure 5.

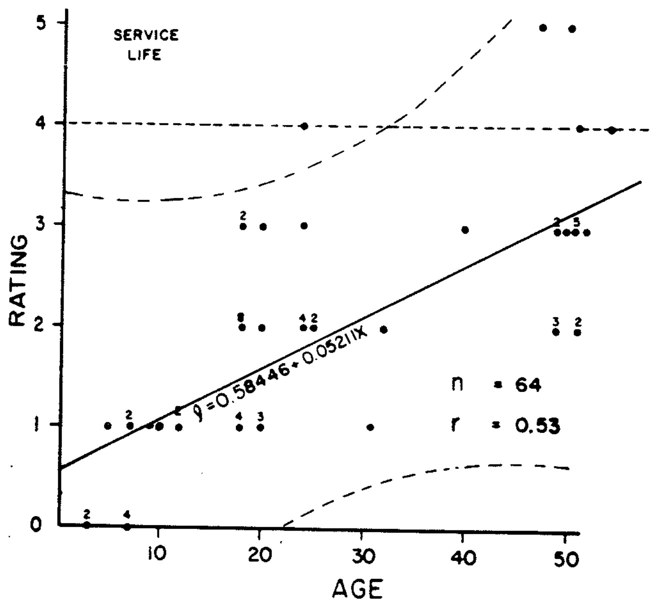

FIGURE 5 Condition versus age for RCP.

The independent variables pH, stream flow, and age all had a significant effect on condition at the 1 percent level.

Only two RCPs were rated as condition 5. This does not mean that RCPs that rated below 4 or 5 have not been replaced. However, the replacements for many sites were the result of frost action on the end sections or barrels of the culverts. It should be noted these older RCPs were 4-ft sections, and this may explain why the frost action destroyed the mechanical integrity of these structures.

Because a number of the RCPs inspected in 1972 and 1973 have been replaced (those rated 4 and 5 at that time), a quote from the 1974 report (2) noted the following:

> Where concrete pipes were located in an environment which was defined as runoff from wooded swampland and which had a pH of 5.3 or lower there was evidence of reduced life expectancy. When concrete pipe was located at a site where it was subject to runoff from the aforementioned condition and prone to being submerged in stagnate water for portions of the year, there were results to suggest this type of environment causes a more rapid deterioration of concrete pipe. Of the 6 pipes which were in this environment, 4 were rated in condition 3 through 5. The runoff from wooded swampland accounted for 40 percent of the pipes rated in the 3 through 5 category. The pH of the water for these six pipes range from 5.3 to 4.3, which would indicate concrete deterioration when the pH is this range or lower.

Experimentally Installed Drainage Structures

The data base from the experimental installations was too small to provide reasonable service life projections. Therefore, no statistical analyses were completed for these culverts.

Aluminum-Coated Corrugated Metal Pipe

The Maintenance Division of MeDOT requires the rerolling of the culvert ends to provide a positive locking mechanism for culvert installations. The rerolled portions of these 3-year-old culverts indicated that the aluminum coating was overstressed. The overstressing of the aluminum coating resulted in extensive oxidation for the sections of culverts that had been rerolled. This problem may shorten service life.

There was evidence of holidays in the aluminum coatings, which had allowed oxidation of the steel beneath the aluminum coating. How rapidly deterioration will develop at these holidays was difficult to determine because these culverts have been in service only a short time. It appears that the aluminum coating provides only a physical barrier and provides little sacrificial action, as does the zinc coating.

The majority of the culverts installed were fabricated by welded seam. For these culverts, the area adjacent to the weld displayed evidence of oxidation apparently caused by splatter from the welding. One installed pipe that was fabricated by the lock-seam method displayed no evidence of oxidation at the lock-seam.

Aluminum-Zinc-Coated Corrugated Metal Pipe

The evaluation completed in 1978 (5 years) indicated that ALZCCMP was performing better than zinc coating because ALZCCMPs were rated 1 and the zinc coatings were rated 2 for all sites. The 1981-1982 evaluation indicated there had been a more rapid deterioration of the aluminum-zinc coating for the 4 years following the 1978 evaluation than for the first 5 years. This apparent increase in deterioration may have been the result of a relatively thin coating (0.6 oz/ft^2).

The aluminum-zinc coating has performed better than the zinc coating at sites where both coating systems were installed.

Polymeric-Coated Corrugated Metal Pipe

The two field inspections (at 5 and 10 years) found no delamination of the polymeric coating from the underlying zinc coating, and the condition of the effluent side was rated as 0 or nearly original condition. The soil side of the culvert was zinc coated, and the 10-year evaluation was rated between 2 and 3. For the soil side, minor to moderate pitting was evident for that portion of the culvert that projected beyond the slope and was in the water during most of the year.

Epoxy-Coated Corrugated Metal Pipe

The two post-epoxy-coated culverts were 2 years old, and both were rated 0 or nearly original condition. One pipe was located in tidal water and the other in inland water.

DISCUSSION OF RESULTS

From the results obtained in the study it appears that the aluminum-alloy culverts provided the best durability in the metal pipe category. As previously stated, the aluminum culvert pipes have certain structural disadvantages, in that they did not always provide the stiffness desired for certain installations.

The results of this study indicate that only aluminum-alloy culvert pipe and aluminum structural plate should be used in tidal waters (seawater).

Where RCPs have been replaced, it was primarily the result of frost action destroying the mechanical integrity of the structure. The loss of mechanical integrity may have been primarily caused by the older RCPs being fabricated in 4-ft sections; thus they were more susceptible to movement than the heavier 8-ft sections currently used. For those RCP sections that had been removed from service and were inspected later, none was rated poorer than 3. As noted earlier, low pH (5.3 and lower) appeared to soften the concrete and cause deterioration.

A comparison of estimated service life for the various culvert materials and coatings is shown in Figure 6. Aluminum alloy and asbestos-bonded pipes were not included in Figure 6 because of a limited data base and a limited time in service. These estimated values of service life should be reasonably accurate for Maine. The pH levels for the inland waters of Maine generally range from 5.0 to 7.5, with 6.5 to 7.0 being the more normal readings. The resistivity values for the soils adjacent to the culverts were generally 10,000 ohm-cm or greater. In reviewing the effects of resistivity early in the study, little or no correlation was found with condition. This may have been the result of higher readings, with most readings being greater than 10,000 ohm-cm.

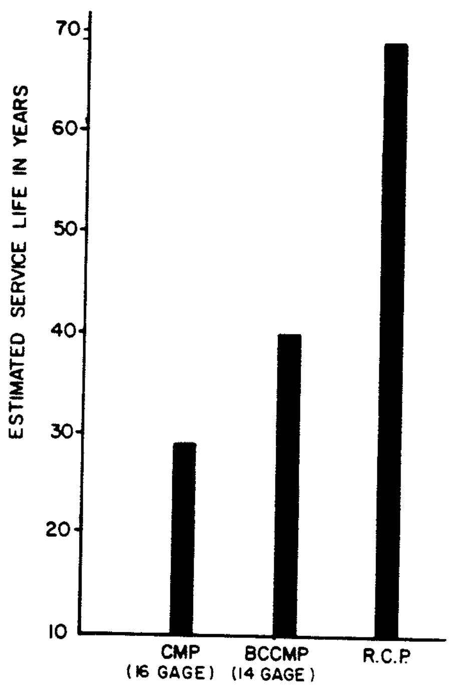

FIGURE 6 Estimated service lives for various culverts for inland waters in Maine.

CONCLUSIONS

The conclusions developed from this study for culverts in Maine are as follows:

1. The aluminum-alloy corrugated metal pipes for both tidal and inland waters appeared to provide the longest service life in regard to corrosion and deterioration. An estimated service life for the aluminum culverts for inland waters in Maine should be more than 50 years based on average metal loss per year.
2. RCPs were found to have an estimated service life of approximately 65 to 70 years for inland waters in Maine.
3. BCCMPs (14 gauge) were found to have a service life of 40 years for inland waters in Maine.
4. CMPs (16 gauge) were found to have a service life of 28 years for inland waters in Maine.
5. ACP was found to be performing satisfactorily, but because of the small sample size, it may be misleading to extrapolate the service life.
6. The estimated service lives for the experimentally installed culverts--ALCCMP, ALZCCMP, polymeric-coated corrugated metal pipe, and post-epoxy-coated corrugated metal pipe--were not determined. The preliminary data for the polymeric-coated pipes and the post-epoxy-coated pipes indicated satisfactory performance.

REFERENCES

1. K.M. Jacobs. Aluminum Culvert Corrosion. Technical Paper 76-5. Maine Department of Transportation, Augusta, Oct. 1976.
2. K.M. Jacobs. Culvert Life Study. Technical Paper 74-1. Maine Department of Transportation, Augusta, Jan. 1974.

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