Field Performance of Protective Linings for Concrete and Corrugated Steel Pipe Culverts

JOHN OWEN HURD

ABSTRACT

In this paper information is provided regarding the durability of protective linings for concrete pipe and galvanized corrugated steel pipe (6 x 2-in. and 2.67 x 0.5-in. corrugations) used for culverts at corrosive and abrasive sites in Ohio. The performances of epoxy-coated concrete pipe, polymeric-coated corrugated steel pipe, and asbestos-bonded bituminous-coated-and-paved corrugated steel pipe have been monitored for the past 10 years. Observations and conclusions made to date are reported. All three materials have provided satisfactory protection of base pipe material at study sites, except for polymeric coating at abrasive sites. The performance of other types of less frequently used protective linings are discussed to a limited extent.

Material durability is an important factor in the determination of what type of pipe is selected at specific culvert sites. Before 1971 no accurate method of predicting the service life of culvert pipe materials in Ohio was available. Pipe selection was based on the experience and subjective judgment of the designer.

Published reports on the durability of culverts in other states were reviewed (1-9). It was noted that the effects various environmental parameters had on culvert durability varied widely among the results reported by the different states. Because of these varied results and because environmental conditions in Ohio were unlike those in any of these other states, the Ohio Department of transportation (ODOT) decided to evaluate culvert pipe durability in Ohio.

In the fall of 1971 ODOT began a comprehensive and continuing program to evaluate the field performance of various types of pipe and pipe protection used for culverts in Ohio. Part of this program has involved the periodic investigation of the performance of epoxy-coated concrete pipe, polymeric-coated galvanized corrugated steel pipe, and asbestos-bonded bituminous-coated-and-paved corrugated steel pipe. Earlier reports (10-12) published by ODOT and FHWA provide information on these linings available at the time of their publication. This report provides updated information obtained from inspections in June and July of 1983.

FIELD INSPECTION

A total of 26 epoxy-coated concrete pipe culverts in Ohio, 57 polymeric-coated corrugated steel pipe culverts in Ohio, and 38 asbestos-bonded bituminous-coated-and-paved corrugated steel pipe culverts in Indiana, Kentucky, and Ohio were inspected one or more times between 1972 and present.

The culvert sites were primarily located in those areas of the state that had more aggressive environmental conditions. Their locations are shown in Figure 1. The following data pertinent to culvert durability were collected at each site:

1. Pipe size, material type, and wall thickness;
2. Type of pipe protection;

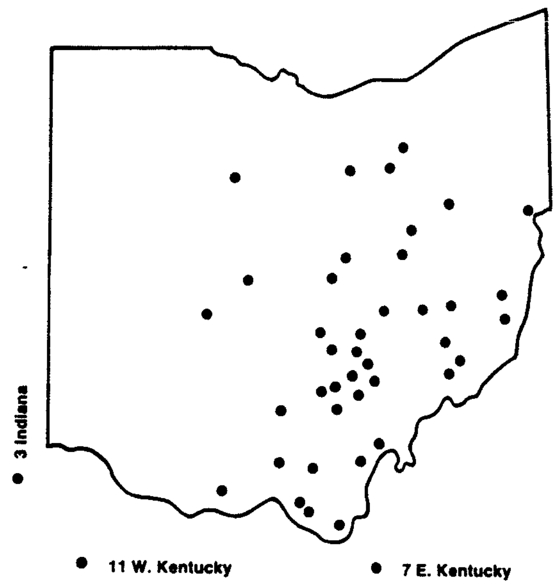

FIGURE 1 Culvert locations.

3. Depth and velocity of dry weather flow;
4. Presence of abrasive material and apparent effect;
5. Amount and type of sediment or debris or both;
6. pH of water; and
7. Description of protection and protection rating (see Table 1).

PERFORMANCE OF EPOXY-COATED CONCRETE PIPE

Epoxy-coated concrete pipe has been used for the past 11 years in Ohio for corrosive culvert sites

TABLE 1 Protection Ratings

Rating	Description
Excellent	Condition as constructed
Very good	Slight erosion of paving or wear on coatings; no significant loss of interior protection
Good	Slight loss of interior protection (isolated areas of loss at ends, joints, or seams); significant erosion of paving to top of corrugations, but no exposed corrugations
Fair	Protection loss to the point where significant amounts of the base pipe are exposed
Poor	Protection failure (no longer useful)

Note: Ratings are based on considering only the lower one-half of the conduit.

(water pH of 4.5). Its use was prompted by the non-availability of vitrified plate-lined concrete pipe, which had previously been used successfully for harsh environmental conditions (10). The current ODOT specification for epoxy-coated concrete pipe is as follows.

> 706.03 Reinforced Concrete Pipe, Epoxy Coated. Type A pipe shall conform to 706.02 and Type B shall conform to 706.04 with the following additions: In the plant, the interior barrel and joint surface areas of the concrete pipe shall be prepared so as to remove all forms of oil, laitance and other deleterious materials and then be lined with a high-build, polyamide-cured, 2-component coal tar epoxy coating, Military Specification MIL-P-23236. The lining compound shall be sprayed to obtain a continuous and relatively uniform and smooth lining with a minimum dry film thickness of 0.03 inches. All coated pipe shall be free of surface irregularities such as air bubbles, delamination, lumping, sagging, blistering, pinholing, or porosity in the coating film.

A compilation of the data collected from the inspections of the 26 epoxy-coated concrete culverts installed to date in Ohio is given in Table 2. All 14 of the 11-year-old culverts were located on one project. The coatings for these 14 culverts appeared to have been brushed on thicker than necessary rather than sprayed on as required by current specifications. In general, flows at the sites ranged from nonabrasive to moderately abrasive. Seven culverts were fully lined, five culverts had the bottom one-half coated, nine culverts had the bottom one-third coated, and five culverts had both the bottom and top one-thirds coated. No reason can be given for coating the top one-third of the last five pipes, except error.

The protection on all but one of the epoxy-coated concrete culverts was rated very good or excellent at the time of last inspection. The one culvert with protection rated poor was a relatively new (4-year-old) 8-ft extension of an existing vitrified lined concrete pipe. At the time of inspection the flow conditions were mild (pH = 7.1, no abrasive material).

Other than the one culvert with a poor protection rating, the protection on all culverts 7 years old or younger was rated excellent. The protection on the 11-year-old culverts was rated very good. No other measured parameter except age appeared to have an effect on the performance of the epoxy coatings.

Because of the preceding observations and the limited age range of culverts studied, no in-depth statistical analyses were performed to develop a predictive model for estimating the service life of epoxy coatings. However, there were observations made in the field that provide information on factors that affect the performance of epoxy coating.

1. Slight peeling was observed along the flow interface at the pipe ends (last 1 or 2 ft where the pipe interior was exposed to direct sun) on 5 of the 14 culverts that were 11 years old.
2. Substantial peeling was observed on the top of pipe sections that extended beyond the roadway embankment on all five of the 11-year-old culverts that had the top one-third of the pipe coated. However, no peeling was observed on the top of pipe sections covered by the fill at these locations. Some peeling was also noticed on the edge of the bottom one-third of the paving on end sections of some of the 11-year-old culverts.
3. Plant markings on the one pipe with poor rated protection indicated that the pipe section was manufactured 3 years before installation.

It can be concluded from the first two observations that the long-term exposure of pipe sections to sunlight has a detrimental effect on the adherence of eooxy coating.

The third observation suggests two possible reasons for the poor coating performance at that one site. Had the pipe section been coated at the time of manufacture and been exposed to direct sunlight in storage for 3 years, coating performance would have been adversely affected. If the coating were

TABLE 2 Data for Epoxy-Coated Concrete Pipe

Size (in.)	Age (yr)	pH	Flow Depth (in.)	Flow Velocity	Abrasive Material	Rating
42	1	3.4	2.5	Rapid	Few rocks	Excellent
48	1	4.3	2.0	Rapid	None	Excellent
21	1	4.6	2.0	Moderate	None	Excellent
30	3	7.3	0.5	Moderate	None	Excellent
36	5	4.6	1.0	Slow	Gravel	Excellent
30	5	3.6	0.2	Slow	Gravel	Excellent
53x83	7	3.3	0.5	Slow	Gravel	Excellent
42	7	3.3	0.5	Slow	Gravel	Excellent
48	6	3.3	2.0	Rapid	Few rocks	Excellent
48	5	6.7	3.0	Rapid	None	Poor
27	2	6.9	1.0	Moderate	Gravel	Excellent
30	2	7.4	0.5	Moderate	None	Excellent
33	11	6.2	0.3	Moderate	None	Very good
30	11	6.1	0.3	Slow	None	Very good
48	11	4.3	1.5	Slow	None	Very good
27	11	6.3	0.2	Slow	None	Very good
24	11	5.3	0.2	Slow	None	Very good
30	11	6.2	1.0	Slow	None	Very good
42	11	6.8	0.5	Slow	None	Very good
48	11	6.9	0.1	Slow	None	Very good
15	11	6.4	0.5	Moderate	None	Very good
60	11	3.7	3.0	Moderate	None	Very good
27	11	6.3	2.0	Slow	None	Very good
36	11	6.5	1.0	Slow	None	Very good
24	11	6.6	0.1	Slow	None	Very good
27	11	6.3	0.1	Slow	None	Very good

applied to a 3-year-old pipe without proper preparation of the pipe surface, a poor bond between the two materials would result. In either case it would appear that lack of proper quality control was the main cause of poor coating performance at this site.

PERFORMANCE OF POLYMERIC-COATED CORRUGATED STEEL PIPE

Polymeric coating (per AASHTO specification M 246) of corrugated steel pipe has been used by ODOT on an experimental basis for the past 14 years. Of the 57 culverts studied, 4 are Nexon coated supplied by U.S. Steel, 48 are Nexon coated supplied by a local pipe fabricator, 3 are Beth-Cu-Loy PC coated, and 2 are Plasticote coated. A compilation of the data collected from inspections performed to date on these culverts is given in Table 3. In general, flows at the sites ranged from nonabrasive to severely abrasive.

The protection ratings for these culverts ranged from excellent to poor. Culverts with protection rated poor ranged in age from 1 to 11 years. Because of the short period of time between the last field inspection and the writing of this report, no detailed analyses of data have been performed to establish a model for predicting service life for polymeric coatings. However, several observations were made on which conclusions can be drawn regarding the durability of polymeric coating.

Abrasiveness of flow appeared to be the major environmental factor affecting the durability of polymeric coatings. The abrasiveness of flow at each site was qualitatively rated by the reporter. When detailed statistical analyses are performed, an attempt will be made to quantitatively determine values for this parameter. All nine of the poor rated culverts were at abrasive sites that had constant low pH dry weather flow and streambed loads with numerous rocks of fist size and larger. Seven

TABLE 3 Data for Polymeric-Coated Corrugated Steel Pipe

Size (in.)	Age (yr)	pH	Flow Depth (in.)	Flow Velocity	Abrasive Material	Rating
36	10	6.7	0.8	Slow	None	Very good
30	10	7.1	0.0	None	Stones	Very good
36	4	7.2	1.0	Slow	None	Very good
36	10	7.9	0.8	Moderate	Gravel	Good
30	10	7.7	1.0	Moderate	Gravel	Very good
24	11	7.8	0.5	Slow	None	Very good
36	11	7.9	2.0	Slow	None	Good
36	10	8.1	5.0	None	Few rocks	Good
36	10	8.1	0.6	Slow	Gravel	Fair
24	11	7.0	0.0	None	Rocks	Good
24	11	7.0	0.0	None	Rocks	Good
24	13	3.0	1.0	Moderate	None	Very good
36	11	6.2	1.5	Moderate	Gravel	Good
24	11	7.5	0.0	None	None	Excellent
24	10	6.7	0.0	None	Gravel	Good
48	4	6.8	0.5	Moderate	None	Very good
24	9	6.9	1.0	Moderate	None	Very good
24	9	6.7	1.5	Moderate	Gravel	Very good
24	5	7.1	0.6	Moderate	Small rocks	Good
24	11	7.0	0.0	None	None	Very good
30	12	7.5	2.6	Rapid	None	Good
30	10	6.1	1.0	Moderate	Medium rocks	Poor
36	11	3.2	2.1	Moderate	Medium rocks	Poor
24	10	3.1	1.2	Rapid	Large rocks	Poor
36	12	4.1	1.5	Moderate	Medium rocks	Poor
36	5	3.3	0.9	Moderate	Few rocks	Very good
24	11	3.0	1.2	Moderate	Few rocks	Poor
24	11	6.2	0.0	None	None	Excellent
24	9	6.2	0.2	Slow	Gravel	Very good
36	9	5.9	3.0	Slow	None	Good
54	5	7.0	3.0	Moderate	Medium rocks	Very good
24	12	2.9	2.0	Rapid	Medium rocks	Poor
24	11	6.5	0.5	Slow	None	Very good
36	10	6.7	1.0	Slow	Gravel	Good
30	11	6.5	0.8	Slow	Small rocks	Very good
54	11	3.2	3.0	Rapid	Medium rocks	Poor
24	11	5.0	0.0	None	None	Good
36	10	3.0	1.0	Moderate	None	Good
24	10	3.1	1.1	Moderate	Few rocks	Very good
24	11	2.9	1.0	Moderate	Few rocks	Very good
24	11	2.8	1.3	Moderate	Few rocks	Very good
30	9	5.7	0.4	Slow	Medium rocks	Poor
30	10	7.4	0.6	Slow	Gravel	Good
36	9	3.8	1.5	Moderate	Gravel	Good
30	13	2.8	1.0	Moderate	None	Very good
36	12	6.6	1.0	Moderate	Gravel	Very good
30	12	3.0	3.0	Rapid	None	Very good
36	11	3.1	1.0	Moderate	None	Very good
66x44	10	4.3	2.1	Moderate	Medium rocks	Good
30	14	3.6	1.9	Rapid	Large rocks	Poor
15	1	7.5	0.0	None	None	Excellent
15	2	7.1	0.0	None	Gravel	Excellent
15	2	7.4	0.0	None	Medium rocks	Excellent
15	1	3.4	0.0	None	None	Excellent
15	1	6.5	0.0	None	Gravel	Excellent
15	2	-	0.0	None	None	Excellent
15	2	7.0	0.0	None	None	Excellent

additional culverts have experienced wear on corrugation tops to the point where the base pipe has been exposed. At four of these culverts delamination has begun at the exposed areas. The pH of the flow did not appear to affect the coating. However, more acidic flow did appear to accelerate delamination where the base pipe was exposed by abrasive wear or by other problems noted later herein.

Other observations were made that relate to problems unique to the protection system.

1. Forming of the lock-seam in helically corrugated culverts appears to have a detrimental effect on the bond between the plastic and steel along the seam. Delamination along the lock-seam has been noted on 24 of the 48 lock-seam culverts. These problems were first noticed at the time of installation for some culverts and at anywhere from 1 to 13 years for others.
2. Exposed edges at pipe section ends and plate edges (in riveted pipe) are prone to delamination. Significant delamination at exposed edges has occurred at 20 sites.
3. Rivets on annular corrugated riveted pipe are unprotected because the plastic is applied to sheet steel before fabrication.

Bituminous paving of the inverts has been suggested to alleviate the problems with abrasion. However, only one 4-year-old culvert inspected had a bituminous paved invert. Therefore, no estimate can be made as to how long paving will prolong the life of the protection system.

PERFORMANCE OF ASBESTOS-BONDED CORRUGATED STEEL PIPE

Asbestos-bonded bituminous-coated-and-paved corrugated steel pipe has been used for the past 12 years by ODOT for corrosive (water pH of 4.5) culvert sites. The current ODOT specification for this material is as follows.

> 707.09 Asbestos Bonded Bituminous Coated Corrugated Steel Pipe and Pipe Arches. These conduits and coupling bands shall conform to AASHTO M 36 for base metal and 707.01 and 707.02 for fabrication where applicable. The conduits shall be formed from sheets which have been coated on both sides with a layer of asbestos fibers, applied in a sheet form by pressing them into a molten zinc bonding medium. Immediately after solidification of the zinc bonding medium the asbestos fiber shall be thoroughly impregnated with a bituminous saturant. The finished sheets shall be free from blisters and unsaturated spots. The asbestos-impregnated sheets shall then be corrugated and fabricated into pipe. After fabrication, the pipe shall be coated inside and out with a bituminous material complying with the requirements of AASHTO M 190, Type C.

Seventeen culverts 6 years of age and older installed by ODOT were inspected. To supplement this data, 21 culverts in Kentucky and Indiana were also inspected. The out-of-state sites were similar in environment (hilly coal mine areas) to the Ohio sites. A compilation of the data collected for inspections performed to date on these culverts is given in Table 4. In general, the sites ranged from nonabrasive to severely abrasive.

The protection ratings for the asbestos-bonded culverts at the time of the last inspection ranged from good to excellent. Because the bituminous paving at all sites was still providing adequate protection for the base pipe, no in-depth analyses of data were performed to establish a method to predict service life for this protection method.

Several observations were made in the field that provide information on factors that affect the performance of asbestos-bonded bituminous coating and paving.

1. None of the culverts inspected revealed any sign of adherence problems.
2. Where the depth of dry weather flow or more frequent storm flows exceeded the height of the paving, the coating was eroded enough for the base pipe to be exposed at a few isolated spots after 5 to 10 years.
3. Abrasive flow caused erosion in the paved inverts in some cases, but exposure of the pipe corrugations was confined to small areas at pipe section ends.

It can be concluded from the first observation that asbestos bonding alleviated the adherence problems common to conventional bituminous protection (10). The second and third observations indicate that bituminous paving is subject to abrasive wear. Erosive loss of paving appears to be at a slow rate when the paving is not overtopped by dry weather or more frequent flood flows. Extension of the paving could improve the performance of the protection system.

PERFORMANCE OF OTHER TYPES OF PIPE PROTECTION

Several other types of culvert protection were observed during field inspections. Although the amount of data collected for each type is not sufficient to perform statistical analyses, observations made are given in the following sections.

Vitrified Clay Liner Plates for Concrete Pipe

Fourteen vitrified clay-lined culverts ranging in age from 3 to 12 years were inspected in detail and several others were observed. Most of these were installed in extremely acidic conditions. To date, the protection is still in very good condition.

Concrete Field Paving of Concrete Pipe

Ohio has field paved some deteriorating concrete pipe culverts at corrosive sites with concrete paving to prolong the life of the pipe. However, this has proved to be a stopgap measure, with the cast-in-place concrete paving deteriorating much more rapidly under acidic flow than the original invert.

Coating and Field Paving of Structural Plate Pipe

In general, bituminous coating of structural plate pipe applied either in the field or at the factory has performed poorly. Field paving with bituminous sand asphalt has not performed well, probably because the proper compaction of this material is extremely difficult to obtain. Concrete field paving has performed well where properly poured and anchored to the pipe. In low pH areas concrete paving with a vitrified clay-lined trough has performed satisfactorily.

TABLE 4 Data for Asbestos-Bonded Corrugated Steel Pipe

Size (in.)	Age (yr)	pH	Flow Depth (in.)	Flow Velocity	Abrasive Material	Rating
18	25	5.0	0.0	None	Few rocks	Very good
18	25	3.6	0.5	Moderate	Gravel	Very good
24	5	7.8	0.0	None	None	Very good
36	5	6.8	2.0	Slow	None	Good
24	5	7.6	0.5	Moderate	Gravel	Excellent
43x27	5	7.3	1.0	Moderate	Gravel	Excellent
36	5	7.2	0.5	Slow	None	Very good
24	11	6.2	0.2	Moderate	Gravel	Very good
48	11	5.2	0.1	Rapid	None	Very good
24	11	5.8	0.0	None	None	Very good
24	11	2.7	0.1	Rapid	None	Good
42	7	2.6	0.0	None	None	Very good
65x40	7	2.5	0.5	Moderate	None	Good
58x36	7	4.2	0.0	None	None	Very good
30	8	3.0	0.0	None	None	Very good
36	8	2.4	0.2	Moderate	Small rocks	Good
30	8	6.0	0.1	Slow	None	Very good
36	8	8.5	0.0	None	Small rocks	Very good
48	22	2.3	0.5	Rapid	Small rocks	Good
48	22	2.4	0.0	None	None	Very good
36	7	2.8	0.0	None	None	Very good
120	7	-	6.0	Moderate	Medium rocks	Very good
18	9	5.0	0.2	Moderate	None	Excellent
15	10	3.3	2.0	Rapid	Few rocks	Excellent
78	7	5.8	2.0	Moderate	None	Very good
65x40	10	5.5	3.0	Moderate	Few rocks	Very good
48	6	6.0	3.0	Rapid	None	Very good
84	6	3.1	2.0	Rapid	Rocks	Good
54	6	6.3	3.0	Rapid	Rocks	Very good
36	6	5.8	1.5	Moderate	None	Excellent
108	6	3.2	4.5	Rapid	Rocks	Very good
72	6	3.2	3.0	Rapid	Rocks	Very good
81x59	6	3.2	2.0	Moderate	Rocks	Very good
24	8	3.4	1.0	Moderate	Gravel	Very good
96	8	3.6	2.5	Rapid	Rocks	Very good
72	8	6.3	1.5	Moderate	Rocks	Good
54	8	3.5	1.2	Moderate	Rocks	Very good
48	12	4.5	1.3	Rapid	Few rocks	Very good

CONCLUSIONS

Based on the observations made in the previous sections, the following conclusions were made regarding the performance of the protective linings studied.

1. Properly applied epoxy coating as specified by ODOT provides satisfactory protection for concrete pipe at low pH sites with nonabrasive to moderately abrasive flow.
2. Long-term exposure of the epoxy coating at culvert ends to direct sunlight has a detrimental effect on coating adherence. Long-term exposure of epoxy-coated pipe section exteriors to direct sunlight has a detrimental effect on coating adherence. However, overall culvert performance is not affected because the extent of the area affected is limited.
3. Abrasive flows are detrimental to polymeric coating performance.
4. Forming of the lock-seam in helically corrugated pipe can create a weakness in the bond between the plastic and metal in polymeric-coated steel pipes.
5. Exposed edges on polymeric-coated pipe are prone to delamination.
6. Low pH flow accelerates delamination of polymeric coatings where the base pipe is exposed.
7. Where delamination along the lock-seam does not occur, polymeric coating provides satisfactory protection of corrugated steel pipe at nonabrasive low pH sites.
8. Asbestos bonding alleviates adherence problems common to conventional bituminous protection of corrugated steel pipe.
9. Abrasive flow is detrimental to the performance of asbestos-bonded bituminous coating and paving, especially where dry weather flows overtop the coating-paving interface.
10. Asbestos-bonded bituminous coating with invert paving provides satisfactory protection of corrugated steel pipe at nonabrasive to moderately abrasive low pH sites.

ACKNOWLEDGMENTS

The work was funded by the Ohio Department of Transportation. The author was assisted by many members of ODOT and other organizations. Although lack of space prevents a detailed listing of all who provided assistance, their efforts are nonetheless greatly appreciated.

REFERENCES

1. D.G. Azar. Drainage Pipe Study. Research Report 57. Louisiana Department of Highways, Baton Rouge, 1971.
2. J.L. Beaton and R.F. Stratfull. The Corrosion of Corrugated Metal Culverts in California. Division of Highways, California Department of Public Works, Sacramento, 1959.
3. J.L. Beaton and R.F. Stratfull. A Progress Report on the Study of Culvert Deterioration. Division of Highways, California Department of Public Works, Sacramento, 1969.
4. J.L. Beaton and R.F. Stratfull. Culvert Life. California Highways and Public Works, Jan.-Feb. 1961, pp. 43-47.
5. J.L. Beaton and R.F. Stratfull. Field Tests for Estimating Service Life of Corrugated Metal

Pipe Culverts. Proc., HRB, Vol. 41, 1962, pp. 255-272.
6. J.E. Haviland, P.J. Bellair, and V.D. Morrell. Durability of Corrugated Metal Culverts. In Highway Research Record 242, HRB, National Research Council, Washington, D.C., 1968, pp. 41-66.
7. L.W. Hyde et al. Detrimental Effects of Natural Soil and Water Elements on Drainage Structures in Alabama. HPR Report 40. Alabama Department of Highways, Montgomery, 1969.
8. H.E. Worley. Effectiveness of Bituminous Coatings on Corrugated Metal Pipe. State Highway Commission of Kansas, Topeka, 1970.
9. H.E. Worley and C.F. Crumpton. Corrosion and Service Life of Corrugated Metal Pipe in Kansas. In Highway Research Record 412, HRB, National Research Council, Washington, D.C., 1972, pp. 35-40.
10. D.G. Meacham, J.O. Hurd, and W.W. Shisler. Ohio Culvert Durability Study. Report ODOT/L&D/82-1. Ohio Department of Transportation, Columbus, 1982.
11. J.O. Hurd. Field Performance of Epoxy Coated Concrete Pipe in Ohio. Report ODOT/L&D/83-2. Ohio Department of Transportation, Columbus, 1983.
12. W.T. Young. Evaluation of Highway Culvert Coating Performance. Report FHWA/RD-80/059. FHWA, U.S. Department of Transportation, 1980.

Publication of this paper sponsored by Committee on Hydrology, Hydraulics and Water Quality.

Field Performance of Concrete and Corrugated Steel Pipe Culverts and Bituminous Protection of Corrugated Steel Pipe Culverts

JOHN OWN HURD

ABSTRACT

In this paper information is provided regarding the durability of concrete pipe, galvanized corrugated steel pipe (6 x 2-in. and 2.67 x 0.5-in. corrugations), and bituminous protection (AASHTO M 190, Types A, B, and C) of corrugated steel pipe used for culverts in Ohio. Detailed analyses were performed to evaluate the effects of various environmental factors on the durability of these materials. None of the environmental parameters studied had a significant effect on the performance of the bituminous protection. Loss of adherence to the pipe was the major cause of deterioration of the material. The average lives of bituminous coating and coating with invert paving were 3.16 and 18.71 years, respectively. Water pH and abrasiveness of flow were the only environmental parameters to have a significant effect on the deterioration rate of corrugated steel pipe. Below a value of 7.0, water pH had a significant effect on concrete pipe performance. Predictive equations and graphs are presented that can be used to estimate service lives of concrete and corrugated steel pipe culverts. Information is provided regarding the geographic location of various ranges of environmental parameters found to have a significant effect on culvert durability.

Material durability is an important factor in the determination of what type of pipe is selected at specific culvert sites. Before 1971 no accurate method of predicting the service life of culvert pipe materials in Ohio was available. Pipe selection was based on the experience and subjective judgment of the designer.

Published reports on the durability of culverts in other states were reviewed (1-9). It was noted that the effects various environmental parameters had on culvert durability varied widely among the results reported by the different states. Because of these varied results and because environmental conditions in Ohio were unlike those in any of these other states, the Ohio Department of Transportation (ODOT) decided to evaluate culvert pipe durability in Ohio.

In the fall of 1971 ODOT began a comprehensive and continuing program to evaluate the field performance of various types of pipe and pipe protection used for culverts in Ohio. The major part of this program to date involved an extensive field investigation and statistical analyses of data to evaluate the performance of concrete pipe, galvanized corrugated steel pipe, and conventional bituminous pro-