CULVERT STUDIES

Progress Report No. 4

A Comparative Study of Aluminum and Steel Culverts

by

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(A Cooperative Organization Sponsered Jointly by the Virginia
Department of Highways and the University of Virginia)

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SUMMARY AND RECOMMENDATIONS

The results of a comparative study of aluminum and steel culverts at six test sites throughout Virginia indicate that satisfactory durability can be expected of aluminum pipe under exposure to most of the soil and water conditions in the state. The performance of the bare aluminum culverts suggests that bituminous coating of the pipes or paving of the inverts would be necessary only under severe site conditions. The performance of the steel culverts in the study demonstrates the effectiveness of coating and paving in prolonging the service life of these pipes. The heavy paving layer in the invert of this type of culvert is subject to cracking soon after installation, but the distress is generally serious only at the ends.

The following recommendations are offered.

1. The current policy of the Virginia Department of Highways regarding the use of fully bituminous coated corrugated steel culverts with paved inverts, as stated in Instructional and Information Memorandum LD-68 (R)-11.2 (11/12/68), should be continued. The use of uncoated pipe allowed in the above memorandum is also reasonable.

2. The use of aluminum culvert as an alternate to bituminous coated, corrugated steel culvert with paved invert should be allowed, at least on a number of projects. This action would increase the experience of the Department of Highways and local fabricators and contractors with the product.

3. If desired, paving of the inverts can be required on initial projects, but consideration should be given, whenever possible, to the use of unpaved aluminum culvert, which presents greater economy. Uncoated aluminum should be allowed as an alternate to uncoated steel culvert.

4. A pH of 4.0 should be considered the absolute lower limit for the use of unprotected aluminum culvert. Since the pH value varies with the amount of flow, the suitability of uncoated aluminum culvert should be considered questionable when the pH values range between 4.0 and 5.0.

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In 1961, the Virginia Highway Research Council began a study to evaluate the performance of aluminum and steel culverts at five test sites representing a wide variety of soil and water exposure conditions. A sixth installation, an aluminum culvert, was added to the study in 1967. The evaluation of aluminum as a culvert material has been of considerable interest in recent years, and, because of numerous request for them the Council's printing of earlier reports in the Virginia study has been exhausted. (1, 2, 3) Therefore, this report was prepared to update and summarize the findings of the study.

The report also presents the results of a short-term condition survey of steel culverts on the interstate highways in Virginia. The survey observations provide a broad picture of the performance of bituminous coated culverts with paved inverts.

PURPOSE AND SCOPE

The purpose of this study is to provide the Virginia Department of Highways a recommendation on the use of aluminum culverts. The recommendation will be based on evaluations of the comparative durabilities of steel and aluminum culverts installed on secondary highways at six sites chosen to provide a wide range of exposure conditions.

The evaluation technique has consisted of periodic visual inspections of the culverts to the extent that site conditions permitted and rough chemical analyses of the water flow at each location. No attempt has been made to obtain accelerated results through the altering of grades or other design features. Instead, the test sites are typical in-service installations under low fills on highways with low traffic volumes. The structural adequacy of the culverts has been noted during the inspections, but except for limited deflection readings taken during the installation of the pipes no data have been obtained.

The condition survey of culverts on the interstate highway system has also concentrated on durability. The survey has included 133 steel culverts located throughout Central and Western Virginia.

COMPARATIVE CULVERT INSTALLATIONS

The steel and aluminum culverts were placed side by side at each of the six test sites. The aluminum culverts were uncoated in every instance; the steel pipes were given a full bituminous coating if warranted by site conditions. Details of the installations are summarized in Table I, and the results of chemical analyses of the water at each location are appended.

TABLE I

DETAILS OF ALUMINUM AND STEEL CULVERT INSTALLATIONS

County and Drainage Condition	Date Installed	Diameter (inches)	Gage	Bituminous Coating
Green (Mountain Stream)	9-61	36	12	None
Augusta (Pasture Runoff)	9-61	42	12	None
Wise (Acidic Water)	9-61	30	12	Steel Culvert Coated
Accomack (Brackish Water)	10-61*	36	12	Steel Culvert Coated
Nansemond (Swamp)	11-61	48	12	Steel Culvert Coated
Gloucester (Brackish Water)	11-67	18	16	None

*Both culverts relocated in October 1964.

RESULTS

Comparative Study of Aluminum and Steel Culverts

Accomack County

The two 36-inch diameter culverts at this site on Chincoteague Island are exposed to brackish tidal flow. The culverts always carry a near capacity flow, and at times they are completely submerged. Thus, inspections have been limited to the top portion of the ends of the culverts.

Examination of the top exterior surface of the bare aluminum culvert has shown widespread corrosion in the cladding, which was removed from much of the area inspected within five years after installation. The corrosion is confined to the cladding, and inspections have disclosed no evidence of pitting of the exposed core metal. There is also no evidence of pitting in that portion of the interior of the pipe which can be inspected. It should be emphasized that the lateral spread of the corrosion within the sacrificial cladding is expected.

The bituminous coating and the zinc layer have been removed from the top interior and exterior surfaces of the galvanized steel culvert, and the entire visible surface is rusted. Metal loss through corrosion has not been severe.

The performance of the aluminum culvert is considered equal or superior to that of the steel culvert at this location.

Augusta County

The 42-inch uncoated culverts at this location carry intermittent runoff from a pasture. While the pipes are generally empty, mud staining of the walls indicates that peak flows may reach a depth of 2 or 3 feet. The condition of both culverts at this site is excellent.

Early inspections of the aluminum culvert disclosed a very slight denting of the surface metal, believed to be caused by the passage of stones during a peak flow. The extent of the denting has not increased noticeably, and site conditions are not considered aggressively abrasive. There is no appreciable corrosion of the aluminum.

The only effect of exposure on the steel culvert has been a slight darkening of the zinc layer, which indicates normal weathering. Either type of culvert, uncoated, will serve adequately at this location.

Green County

The uncoated culverts at this site near Dyke, Virginia, are installed in a rocky stream in a hilly drainage area. Stones as large as 6 inches in diameter are transported through the culverts during peak flow.

The passage of stones through the aluminum culvert has caused denting of the surface, and it is likely that some metal is being removed by abrasion. To date, however, there is no evidence of a severe abrasion problem, and the performance of the pipe is entirely satisfactory. The culvert is stained, but it is not appreciably corroded.

Abrasion of the uncoated steel culvert has resulted in removal of the galvanizing from the invert and subsequent rusting. At the last inspection, the culvert was rusted across a width of 2 feet throughout the length of the pipe. Metal loss has not been severe, and the invert remains sound.

Although both culverts are serving adequately, the performance of the aluminum pipe is considered superior to that of the bare steel pipe, because of the absence of corrosion. It seems likely that the performance of the steel culvert would have been improved by paving of the invert.

Nansemond County

This site, which contains two 48-inch pipes, is located at the edge of the Dismal Swamp near Holland, Virginia. The culverts are generally half full of water, and inspections are limited to the top surfaces near the ends of the pipes.

Early inspections disclosed that both culverts were out of round along the central portion of their length. The deformation has not increased noticeably, and it is probably a result of initial settlement. Both culverts are structurally adequate at this time.

The aluminum culvert is stained, but only slight corrosion has been reported. The steel culvert appears to be lightly rusted along the waterline in areas where the bituminous coating has been lost.

The condition of both culverts can be considered satisfactory at this time.

Wise County

The 30-inch bare aluminum and bituminous coated steel culverts at this location near Wise, Virginia, are exposed to runoff contaminated by sulfurous waste from strip mining operations in the area. The acidic water passing through the culverts has a pH as low as 3.2, depending on flow conditions.

The invert of the aluminum pipe was severely pitted within one year after installation and completely removed by corrosion in two years. This failure was not unexpected, as 4.0 is the lower limit of the pH range in which the use of aluminum culvert is recommended.

The invert of the steel culvert has been destroyed by corrosion in those areas where the bituminous coating has been lost, but the coating is generally intact. The edges of the coating are not bonded to the steel, possibly due to undercutting by rusting, and it is inevitable that the corrosion will proceed. However, the bituminous coating has greatly increased the service life of the pipe.

In an effort to find a more suitable material for exposure to highly acidic runoff, a bituminous impregnated fiber culvert and a concrete culvert were installed at the Wise County site in 1963. Acid attack on the invert of the concrete pipe exposed the aggregate and caused spalling of the rim at the outfall end within five years after installation. The comparison of the concrete and coated steel culverts is inconclusive at this time. The bituminized fiber pipe has shown excellent resistance to the adverse effects of the acidic runoff, but, unfortunately, a suitable strength specification for pipes of diameters larger than 8 inches does not exist at present.

Gloucester County

The Gloucester County test site, which is approximately 300 yeards from the Ware River, is exposed periodically to brackish tidal flow. One line of 18-inch diameter aluminum culvert was installed at this location in November 1967 to supplement the observations at the Accomack County site.

At the time of the last inspection (February 1970) the culvert exhibited etching of the cladding on all exposed surfaces, with isolated areas of more severe corrosion in the cladding on the interior surfaces. The performance is considered typical of that expected early in the service life of a culvert exposed to brackish water; it is similar to the early performance of the aluminum pipe in Accomack County.(1)

Condition Survey of Corrugated Metal Pipe Culverts on the Interstate System

During the latter part of 1970, the Research Council surveyed the corrugated metal culverts on the interstate highway system. The current Virginia policy regarding pipe culvert materials on interstate highways allows the use of only concrete pipe on or east of Route 95; concrete pipe or fully bituminous coated steel pipe with paved inverts may be used west of Route 95. Uncoated steel or aluminum pipe may be used under entrances and frontage roads west of Route 95, but little, if any, aluminum pipe is in use on the primary and interstate highway systems. Thus, the condition survey evaluated the performance of only steel culverts.

Inspections were made of 133 culverts throughout the state. Both coated and uncoated steel culverts were observed, and a clear picture of the effectiveness of the bituminous coating and paving emerged.

The general condition of the culverts inspected, most of which were less than 10 years old, was exellent. Of the 111 bituminous coated and paved culverts observed, less than 10 percent showed signs of rusting, and none exhibited severe metal loss. The rusting noted in the bituminous coated culverts was confined to areas where the coating had been removed, generally near the ends of the pipes, and it was not considered a serious problem. A high percentage of the 22 uncoated pipes were rusted, and the results of the survey indicate that the Virginia requirement that steel culverts on higher class highways be fully bituminous coated with paved inverts should be continued.

The bituminous coating on the pipes is not an ideal protective measure, but it is probably the best system routinely available. The deterioration of the coating follows a definite form. Rectangular pattern cracking, shown in Figure 1, develops in the heavy paving layer in the invert early in the life of the culvert, probably due to a combination of oxidation and shrinkage of the asphalt and flattening of the cross section of the pipe. Cracking of the invert paving was in fact, noted in culverts on a portion of Interstate 64 opened in the fall of 1970, although no loss of the protective coating or rusting of the steel was observed. The distress is accelerated

at the ends of the culvert where oxidation is more severe, and the cracks often reach a width of more than $\frac{1}{4}$ inch as shown in Figure 2. The material is generally well bonded to the culvert wall, but the large pieces between the cracks are occasionally removed, as shown in Figure 3, by the force of the flow or the passage of rocks or debris through the pipe. The zone of severe cracking and subsequent loss of the protective coating generally extends a maximum of 5 to 6 feet into the barrel of the culvert. The coating in the interior of the pipe often exhibits a few narrow cracks, but the distress is never serious.

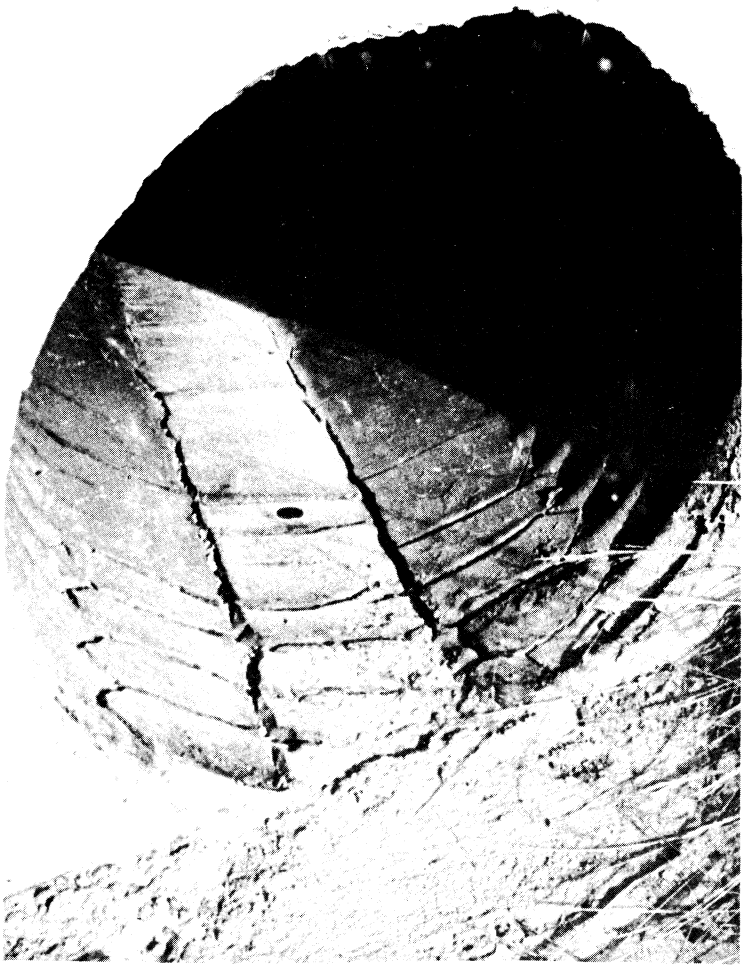

Figure 1. Rectangular pattern cracking of the paving layer in the invert of a steel culvert.

Figure 2. Widening of cracks in the paved invert at the end of the culvert due to oxidation of the bituminous material.

Figure 3. Large sections of the invert paving layer forced out of the culvert.

DISCUSSION

It is believed that the wide range of exposure conditions represented by the six sites included in the comparative study provides a good indication of the relative durability of uncoated aluminum pipe. The performance of the aluminum culvert is considered superior to that of the steel culvert in the Greene County installation, and, after nine years of service, the aluminum pipes are proving as durable as the steel pipes at the Augusta, Nansemond, and Accomack sites. The study indicates that over much of Virginia soil and water conditions would not be severely corrosive to aluminum culverts. This conclusion is supported by the findings of a survey of 965 culverts conducted by the Aluminum Association. (4)

The adequate durability exhibited by the bare aluminum culverts suggests that, under all but severely abrasive or corrosive conditions, coating of the culvert and paving of the inver may be unnecessary. A similar conclusion, based on evaluations of 34 aluminum culverts, was reached by Haviland, et al, in New York. (5) Abrasion has not proved to be a serious problem at the Greene County installation, which is located in a rocky stream subject to occasional high velocity flows.

The failure of the aluminum culvert exposed to highly acidic water at the Wise County site was not unexpected. Fortunately, such sites are rare in Virginia, and their general locations are known. It would not be advisable to use uncoated aluminum culvert in such an area. A pH value of 4.0 should be considered the absolute lower limit for the use of unprotected aluminum culvert.

The results of both the survey of culverts on the interstate system and the comparative study indicate that use of a bituminous coating and paving of the invert does prolong the service life of a steel culvert. The requirement of the Virginia Department of Highways that steel culverts under high class roads be fully bituminous coated with paved inverts should be continued.

The cracking and subsequent removal of the bituminous coating early in the life of a culvert has been a matter of concern to others.[6] The cracking of the heavy paving layer appears to be related to properties of the bituminous material, and prevention or effective repair of the distress will be difficult. However, as noted previously, the zone of severe cracking and loss of material is generally located at the ends of the culvert.

CONCLUSIONS

1. Evaluations of the durability of aluminum culverts with nine years of service at six sites including a wide range of exposure conditions indicate that a majority of the soil and water conditions in Virginia are not severely corrosive to uncoated aluminum culverts.

2. The adequate durability exhibited by the bare aluminum culverts suggests that, under all but severely abrasive or corrosive conditions, coating of the culvert and paving of the invert may be unnecessary.

3. The only failure of an aluminum culvert occurred under exposure to a stream contaminated with sulfurous mine waste. The pH at this location was well below 4.0 and severe corrosion of the aluminum culvert would be expected.

4. The performance of the galvanized steel culverts indicates that the use of a bituminous coating and paving of the invert does prolong service life.

5. The heavy bituminous paving layer in the invert of a culvert was observed to develop rectangular pattern cracking soon after installation, and large pieces of the material were occasionally forced out of the pipe. However, the zone of severe distress was found to be limited to the ends of the pipe.

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APPENDIX

CHEMICAL ANALYSES OF WATER

Chemical analyses of the water at the test sites were made in the field by means of a portable test kit and a Beckman pH meter. The field procedures were relatively simple, but significant variations in the test data obtained from a single site suggested that the reliability of the equipment might be questionable. Consequently, results obtained through the use of the portable equipment were compared with those of standard laboratory procedures in tests of solutions having known properties. The percent variation of the field equipment results from those of standard procedures for each test are shown below.

Test	% Variation from Standard Procedure
pH	10%
Dissolved Oxygen	20%
Hardness	20%
Calcium	20-50%
Carbon Dioxide	50%
Chlorine	50%

Iron and Hydrogen Sulfide tests were not evaluated.

The results of the comparison with standard tests indicate that, except for pH values, the field data, shown in Table A-I, provide only a general estimate of the chemical properties of the water. The pH readings are considered reliable.

TABLE A-I

CHEMICAL ANALYSIS OF WATER FLOWING THROUGH PIPES

Culvert Location, County	Date of Test	Carbon Dioxide (p.p.m.)	Calcium Hardness (g.p.g.)	Total Hardness (g.p.g.)	Chloride (p.p.m.)	Hydrogen Sulfide (p.p.m.)	Iron (p.p.m.)	Dissolved Oxygen (p.p.m.)	pH
Accomack	8-1-62	10	48	200		0.1	0.6	10	8
	10-1-63	10	--	200		0.1	0.1	8	7.8-7.9
	3-26-64	15-20	31	168		0.1	0.1	9	7.6
	9-3-64	20	35	135		0.1	0.1	5	7.2
	8-17-66	--	55	---		0.1	0.1	10	8.2
Augusta	8-3-62	5	3-8	3-10	37-62	0.1	3.5	10	7
Greene	8-2-62	5	1	2	25, 37	0.1	3.0	10	7.5-8
	10-4-63	15-20	-	2	25	0.1	1.0	--	7-7.3
Nansemond	7-31-62	15-20	1	2-3	50	0.1	3-4	10	6.5
	9-30-63	5	-	3	25	0.1	0.5	4	5.5
	3-26-64	10	1	2	62.5	0.1	0.2	9	6.2
	9-2-64	20	1	3	70.0	0.1	0.3	5-6	5.5
	8-17-66	20	1	2	37.5	0.1	1.0	7-8	6.0
Wise	7-30-62	100-125	8-10	19-26	100	0.1	3-5	10	4.0-4.6
	3-25-64	265	13	34	50	0.1	5.0	10	3.2
	8-31-64	185	20	38	75	0.1	2.0	10	3.2
	8-15-66	170	9	21	50	0.1	3.0	10	3.3

Note: Chemical analysis tests were not performed at the Gloucester County site.