Culvert Durability: Where Are We?

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ABSTRACT

There has been extensive use of culverts under highways for more than 75 years. During that time the states have made more than 90 culvert performance studies. Prediction of the probable service life of all types of culverts is still difficult because of continuing changes in materials, the use of various coatings, and the large number of variables that affect corrosion and erosion. Individual states are continuing to develop guidelines for the service life of concrete, steel, aluminum, plastic, and other types of culverts based on local experience and the performance of materials in other applications. No nationally acceptable relationship between culvert service life and corrosion parameters has as yet been developed. Increasing use of culverts for bridge replacement warrants the development of inspection and maintenance programs for culverts.

Durability is just one of many factors that determine the selection and use of pipe culverts for drainage purposes. In order to put durability into perspective, the substance of a letter written in September 1983 by Kent Allemeier, Chairman of Technical Section 4a of the AASHTO Subcommittee on Materials, to Carl Redel of the Standards Institution of Israel, who requested information on the merits of corrugated metal and concrete pipes, is presented. With Allemeier's permission, the following is excerpted from his letter.

> There are differing opinions on the favorable and unfavorable aspects with each of the kinds of pipe. Basically, the pipe must be designed for the requirements of the location in which it is to be installed, preferably by a competent engineer who is familiar with the economic and environmental concerns of the area.
>
> Following are certain factors which should be considered in relation to selection of a particular kind of pipe. Reference is made to AASHTO specifications for the various pipe materials.
>
> I. Corrugated Steel Pipe (M35/M36M), fabricated from zinc-coated sheet (M218), aluminum-coated sheet (M274), or aluminum-zinc alloy-coated sheet (M289)
>
> A. Advantages
> 1. Reasonably lightweight (for shipping)
> 2. Large range of sizes and shapes
> 3. Range of sheet thickness and corrugations provide appropriate strength
> 4. Fast field assembly and installation
>
> B. Disadvantages
> 1. Decreased flow due to corrugation roughness (except in smooth-lined pipe)
> 2. Loss of metal through abrasion in fast-flowing streams with significant load of sand or rock
> 3. Corrosion of pipe in installations with high or low soil or water pH, and/or low soil or water resistivity
> 4. Requires controlled backfill for proper soil support
>
> C. Other Options
> 1. Corrugated structural plate (M167) may be used for field assembly for large structures
> 2. Polymer-coated corrugated steel pipe (M245) provides some abrasion protection and substantial corrosion protection
> 3. Bituminous-coated or lined pipe (M190) provides added corrosion protection, and lining provides smooth flow line; durability of coating is questionable in some installations
>
> II. Corrugated Aluminum Alloy Pipe (M196) fabricated from aluminum-alloy sheet (M197)
>
> A. Advantages
> 1. Very lightweight (for shipping)
> 2. Large range of sizes and shapes
> 3. Range of sheet thicknesses and corrugations to provide appropriate strength
> 4. Fast field assembly and installation
> 5. Better resistance to corrosion than steel pipe, especially in brackish waters
>
> B. Disadvantages
> 1. Decreased flow due to corrugation roughness (except in smooth-lined pipe)
> 2. Subject to abrasion in fast-flowing streams with significant load of sand or rock
> 3. Generally more costly than steel pipe
> 4. Generally more flexible than steel; requires greater care in installation; not as tolerant of less-than-normal cover
>
> C. Other Options: Corrugated aluminum structural plate (M219) may be used for field assembly of large structures
>
> III. Concrete Pipe--unreinforced (M86), reinforced (M170), reinforced arch (M206), reinforced elliptical (M207), reinforced box sections (M259, M273), etc.
>
> A. Advantages
> 1. Large range of sizes and shapes
> 2. Range of reinforcements, wall thicknesses, and concrete

> strengths to provide appropriate pipe strength
>
> 3. Smooth surface for good flow characteristics
> 4. Not subject to corrosion or abrasion in normal installations
> 5. Rigid pipe more tolerant of poor backfill compaction than corrugated steel pipe
>
> This listing is a superficial coverage of the advantages and disadvantages of corrugated metal and concrete pipe. For more specific enumerations of the advantages of each type of pipe, we suggest that you contact the associations representing each type in the United States.

Mr. Allemeier's letter makes it clear that a large number of factors govern the selection of pipe culverts. There is a best application situation for each kind of culvert currently made available by the producers. This paper is intended to be a general discussion of the state of the art on one of the factors: culvert durability.

CULVERT DURABILITY: WHERE ARE WE?

Durability is defined as the ability to last a long time with retention of original qualities, abilities, or capabilities. Compared to a person's lifetime, many engineering structures last a long time. John Roebling's Brooklyn Bridge just celebrated its 100th birthday. Stone castles and some wood buildings in Europe are more than 500 years old. Parts of the Great Wall of China are some 3,000 years old. Highway culverts are not expected to last this long, but as the highway system in the United States continues to be upgraded, it can be anticipated that with proper care the primary and Interstate roadways could well be in service 100 years from now. Some of the Interstates are already 20 years old. The roadway includes embankments, which are expected to be in service for many years beyond pavement surfaces, which may need repairs or replacement after 20 years. To avoid expensive culvert replacements, a design life that corresponds to the longer life of the roadways should be considered, along with improved inspection and maintenance programs for culverts. Shorter design lives for culverts may be appropriate for less-developed roadways. A required service life for culvert installations should be defined for each project.

During the rapid growth stages of the United States it was sometimes general policy to select and build those types of structures with the lowest first cost, with small regard for future maintenance costs to the owner. As this country is maturing, there is a trend toward considering higher initial costs to reduce future maintenance and replacement. This trend places more emphasis on the cost of engineering structures over their entire life. Some refer to this as life-cycle costing. In a recent editorial in the Engineering News Record, it is stated that "provisions for proper maintenance and design for lowest life-cycle costs have always been important responsibilities of designers" (1). With the inconvenience and expense of temporarily removing a structure from service to permit replacement and repairs, and the high costs of either repairs or replacement, the "proper solutions to the infrastructure problem demand, as stated before, is the design of policies to assure rational long-term programs of maintenance and repair" (1).

The extent of the growing concern for life-cycle costs is also reflected by the Office of Management and Budget (OMB), which states that "where specified in the bidding documents, factors such as discounts, transportation costs, and life-cycle costs shall be considered in determining which bid is lowest" (Attachment O of OMB Circular A-102, Federal Register, August 15, 1979).

Similarly, a recently drafted Supplemental Design Guidance for Conduits by the Missouri Division of the Corps of Engineers (2) states that a life-cycle cost study will be required when the use of certain types of conduits in cohesive soil is proposed.

Determining life-cycle costs for culverts is not simple, partly because of the relatively short history of performance available for a given type of culvert, and partly because the industry is continually advancing by producing new pipe products of different materials. In addition to short performance records, there are also uncertainties of the cost of money over the analysis period. However difficult, proper engineering design should include concern for the costs of building, maintaining, and replacing structures. This concern is reflected by engineers' attempts to predict the useful life of culverts for a wide range of products and service conditions as culverts grow in importance and cost.

Sizes of culverts have grown with the expansion and development of highways. At first culverts were constructed of wooden planks, hollowed logs, and rock and masonry arches. Some of these early culverts usually had short service lives, which corresponded to the short service lives of the roads they served.

Culverts are now made of concrete, steel, aluminum, cast iron, masonry, vitrified clay, plastic, and many composites of these materials. Specifications for some of these are given in Table 1 (3). Sizes range from small-diameter drainage pipes to 50-ft spans.

In bridge replacement programs, large culverts are sometimes a better engineering solution for lowest life-cycle costs (4). There is also increased use of box culverts (concrete, aluminum, and steel) for these applications. At last report more than 1,000 long-span culverts (16 to 50 ft wide) have been installed in the United States alone (5).

Some of the following factors could affect the service lives of large and small culverts:

1. Hydraulics--increase in capacity requirements, wash-outs, leakage and piping, flotation of ends, undermining of end sections, and clogging;
2. Structural--loads (backfill material and vehicle), earth movements, and handling stresses; and
3. Corrosion and abrasion--electrical, chemical, and mechanical.

The main part of this paper is concerned with the present status of understanding and treating corrosion and abrasion effects of culverts.

SERVICE RECORDS

Some historical events in the development of roads and culverts are shown in Figure 1. Concrete and steel culverts have been used under roads for about 75 years. Galvanizing of steel began some 70 years ago; use of aluminum pipe started some 25 years ago; use of plastic pipe began about 7 years ago; and epoxy-coated steel pipe just recently came into use. Along the way there have been a number of material changes, such as the copper content of culvert steel and the cement content of concrete pipe. Some of these changes improved the products; others made the products more competitive. The most dramatic in-

TABLE 1 Current Specifications for Drainage Pipe *(3)*

Pipe Material	Specification			
	AASHTO	ASTM	Federal	Other[a]
Steel				
Galvanized corrugated steel	M 36		WW-P-405	
Corrugated steel structural plate	M 167		WW-P-405	
Precoated, galvanized steel	M 245		WW-P-405	
Aluminum				
Corrugated aluminum alloy	M 196		WW-P-402	
Aluminum alloy structural plate	M 219		WW-P-402	
Concrete				
Reinforced	M 170	C 76		
Reinforced, box sections	M 259	C 789 C 850		
Reinforced, elliptical	M 207	C 507		
Nonreinforced	M 86	C 14		
Cast-in-place, nonreinforced				ACI 346
Reinforced arch	M 206	C 506		
Asbestos-cement	M 217	C 428 C 663	SS-P-331	
Cast iron	M 64	A 142	WW-P-421	
Clay	M 65	C 700	SS-P-361	
Clay liner plates		C 479		
Plastic				
Polyethylene (PE)	M 252	F 405		
Polyvinyl-chloride (PVC)		D 3033 D 3034		
Acrylonitrile-butadiene-styrene (ABS)	M 264	D 2680 D 2751		
Fiberglass-reinforced (FRP)		D 2996 D 2997		
Stainless steel, culvert grade				AISI Type 409

[a] Note that ACI is the American Concrete Institute and AISI is the American Iron and Steel Institute.

1800 First Toll Road
"National Transportation Plan" Gallatin
1820

1840
Concrete Culverts for Railroads
1860

1880 Beginning of Good Roads Movement
Establishment of Office of Road Enquiry (Now FHWA)
1900 Corrugated Metal Culvert — Watson & Simpson
Concrete Pipe for Highway Culverts (Iowa)
1920 2 oz. Galvanized Coating Adopted for Steel Culverts
First Documented Culvert Performance Survey
Multi-plate Pipe and Arch
1940 Asbestos-bonded Asphalt Coating
"Aluminized" Steel Culverts

1960 Aluminum Culverts
Concrete-lined Steel
Gavalume
Plastic Pipe for Highway Culverts
1980 Non-Copper Bearing Steel-Epoxy Coating
ASTM Permits 5 Bags of Cement/cu. yd. in Concrete Pipe
2000 Steel with Plastic Liner

FIGURE 1 Development of roads and culverts in the United States.

crease in lineal feet of culverts has been since 1950, when highway fills became wider and higher, even though the total surfaced road mileage in the United States has increased constantly since 1920 (Figure 2). From this it may be deduced that the major part of the culvert service experience record is less than 35 years (1950 to 1983), including whatever changes in materials have occurred in that time period.

On a more limited basis, experience records go back more than 60 years. Almost all of the state highway organizations have made culvert condition surveys, with some documented surveys as early as 1925. Since that time more than 90 separate culvert condition surveys have been made (Figure 3). These surveys, along with the records of performance of materials in other applications, have been useful

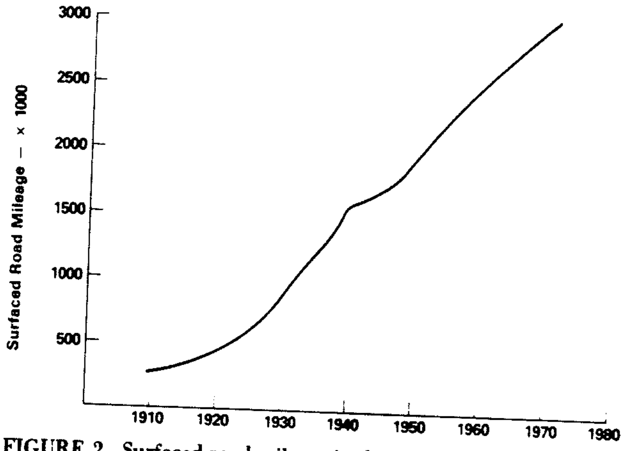


FIGURE 2 Surfaced road mileage in the United States.

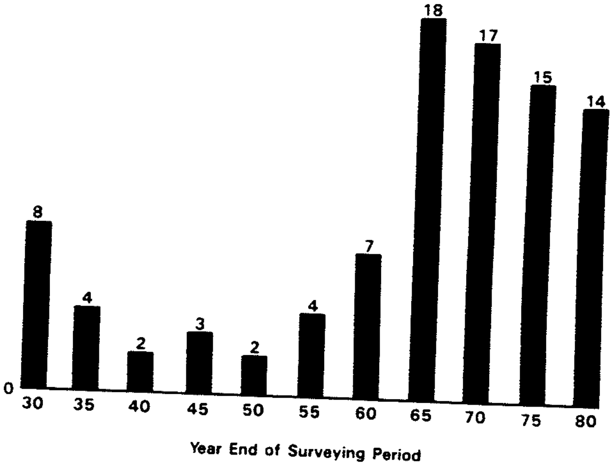


FIGURE 3 Distribution of culvert condition surveys by years.

TABLE 2 FHWA Durability Criteria for Metal Pipe *(7)*

Type of Pipe Listed in Order of Ascending Degree of Durability	Pipe Fabrication per AASHTO Specification	Soil and Water pH (minimum-maximum)	Soil and Water Resistivity[a] (minimum ohm-cm)	Abrasion Rating[b] (maximum)
Galvanized Steel Corrugated Metal Pipe				
Galvanized steel, uncoated	M 36	6-10	3,000	Mild
	M 167	5-6 and 10-12	10,000	
Galvanized steel, bituminous coated	M 36 and M 190	5-12	3,000	Moderate
	M 167 and M 243			
Galvanized steel, bituminous coated with paved invert	M 36 and M 190	5-12	3,000	Substantial
		4-5	10,000	
Galvanized steel, asbestos bonded with bituminous coating with paved invert	Federal specification WW-P-405B[c]	4-12	1,000[d]	Substantial
Aluminum Alloy Corrugated Metal Pipe				
Aluminum alloy, uncoated	M 196[e]	4-9	500[d]	Moderate
	M 219			
Aluminum alloy, bituminous coated	M 196[e] and M 190, and M 219 and M 243	4-9	500[d]	Moderate
Aluminum alloy, bituminous coated with paved invert	M 196 and M 190	4-10	500[d]	Substantial

[a] Minimum soil resistivity determined in the laboratory from a soil sample.

[b] Abrasion ratings are mild, moderate, substantial, and severe.

[c] There is no AASHTO specification for this coating.

[d] Does not apply to saltwater or brackish water when pipe is buried in clean, well-draining soil.

[e] Aluminum alloy alclad 3004-H34 per ASTM B 209.

for establishing guides for the selection of culverts in specific areas, but correlations of culvert condition versus the severity of a specific corrosive environment in the literature do not generally provide satisfactory results on a national basis, apparently because variables not taken into account in individual investigations strongly influence corrosion rates in other areas. For example, corrosion of steel is influenced by hydrogen ion concentration (pH), other ions (sulfides, sulfates, chlorides, nitrates, ammonia, ferrous iron), calcium carbonate in water, electrical resistivity, temperature, oxygen concentration, flow velocity, sulfate-reducing bacteria, climate (wetting and drying), uniformity of backfill, and other.

Application of even these factors can be a problem. Results of a Bureau of Public Roads survey made some years ago determined that corrosion was occurring on 8 out of 140 galvanized corrugated steel pipes, even though the water flow had a relatively neutral pH, with no special chemical property that could contribute to this corrosion (6). Current FHWA durability criteria for steel pipe are given in Table 2 (7).

The performance of concrete pipe can be adversely affected by alkaline (pH 12 and greater) and acid (pH less than 4 to 4.5) conditions, hot distilled (pure) water (leaches cabonates), freezing and thawing, alternate wetting and drying, and sulfates of calcium, sodium, magnesium, potassium, aluminum, and iron.

Combinations of materials that produce concrete most highly resistant to agents of aggression are thoroughly discussed in "Factors Affecting Durability of Concrete Pipe" (8).

The performance of aluminum is known to be related to pH of the water, resistivity of the backfill soil, presence of heavy metals, some kinds of salts, oxygen concentration, flow velocity, and uniformity of the backfill. A recent survey of aluminum culverts in California (9) resulted in the establishment of plans to approve the use of aluminum culverts in nonsaline, nonclay soils of pH between 5.5 and 8.5, with a minimum resistivity of 1,500 ohm-cm. Under certain marginal conditions (pH 5.5 to 8.5 and resistivity of 500 ohm-cm, and pH 5.0 to 5.5 and 8.5 to 9.0 and resistivity greater than 1,500 ohm-cm), aluminum may be allowed on approval of the Transportation Laboratory [Figure 4 (9)]. Guidelines recommended by the Aluminum Association and Kaiser Aluminum were established in 1969 (10). FHWA durability criteria for aluminum pipe (less stringent than California's) are given in Table 2.

Plastic culverts are highly resistant to chemical corrosive agents and abrasion. They do need protection from ultraviolet (uv) sunlight during storage and at culvert ends protruding from the soil backfill. Other considerations might include their potential for burning and for stress-related distress.

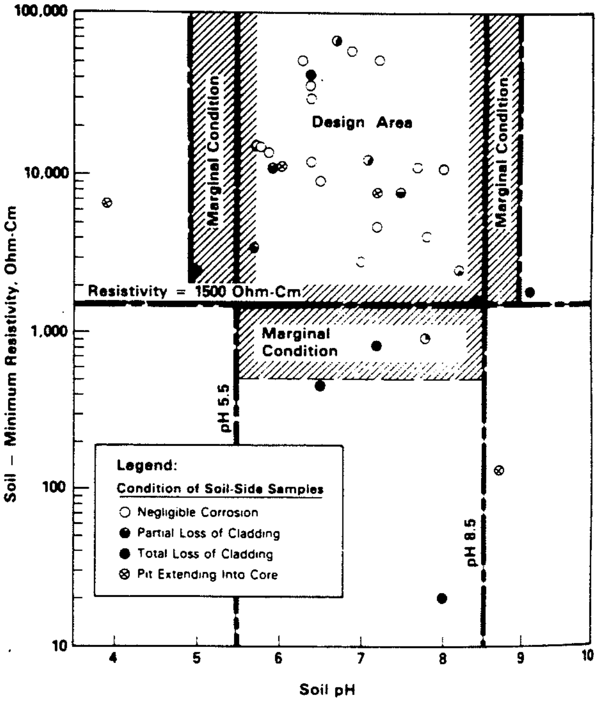


FIGURE 4 Condition of aluminum crown samples versus pH and minimum resistivity of adjacent backfill *(9)*.

The majority of plastic pipe is used for underdrains. However, a recent study indicates that it is appropriate to consider plastic pipe for other transportation drainage applications as follows (11):

Type of Pipe	Suitable Use
PVC smooth-wall	Storm drains and perforated underdrains
PE tubing, corrugated and perforated	Underdrains
ABS composite-wall pipe	Storm drains
ABS pipe	Underdrains

A study by the Corps of Engineers for FHWA (12) indicated that both PVC and PE slotted underdrain pipes performed satisfactorily under heavy repeated loads when installed in compacted granular backfill at 12- and 18-in. depths, respectively.

Other types of materials that may be used for culverts include cast iron, clay tile, masonry, stainless steel, and composite types such as reinforced plastic, foamed cement and plastic, steel with plastic liners, steel with concrete lining, and conventional pipe with a wide variety of coatings.

CULVERT PROTECTION

To extend the life of culverts in corrosive environments, various protective means are employed. The most common are the coatings applied to steel culverts. In addition to 2 oz of zinc galvanizing per square foot (1 oz on each side), a coating of asphalt has been popular in the past. The performance of asphalt coatings, as well as other types, was recently evaluated by a study funded by FHWA (13).

It was determined that most coatings are effective in situations where runoff does not include abrasive debris and the water does not contain a high percentage of soluble salts, particularly chlorides. All organic coatings inspected were subjected to impact and abrasion deterioration, and most deteriorated under wet alkali or salt conditions. Low pH conditions tended to cause disbondment of many coatings by attacking the metal substrate at coating defects. In this study the most effective coating system found was an asbestos-bonded, asphalt-coated, corrugated galvanized steel pipe. One polyvinyl-coated steel culvert and one aluminized steel (T_2) pipe examined were also performing well, and several new types of coatings have been developed since that time, including fusion-bonded epoxy-coated steel and corrugated steel pipe with a PVC liner. Many more coating systems have been considered by the industry, but are usually rejected as either not cost effective or not salable when life-cycle costs are not considered.

Some conclusions from the FHWA-sponsored study on coatings are as follows:

1. Durability problems are encountered with all rotective coatings now commonly used.
2. Alternate methods are available to protect lverts, other than organic coatings, and could ve been used to advantage at many of the locations spected in the field study.
3. Organic coatings are, by themselves, not tisfactory under abrasive stream flow conditions.
4. The durability of polymer coatings depends the amount of salts in the soil or water, the tinuity of the coating, the pH, and the abrasives of the bedload. Improvements are needed in duction techniques to prevent damage that adsely affects performance. Polymer coatings are tisfactory where abrasive flows and high salt ditions are not encountered.
5. Asphalt adhesion to aluminum is poor. This coating would not be satisfactory in abrasive or corrosive environments.
6. Epoxy coatings and vitrified clay liners are effective when used on concrete in acidic streams. They might also be useful on corrugated metal under certain severe conditions.
7. Adhesion between asphalt and galvanized steel can be improved through the use of surface treatments and primers. The benefits of improved adhesion should be evaluated.
8. Asbestos-bonded asphalt coating is more durable than plain asphalt coating, but it is also subject to deterioration in abrasive or high salt environments.
9. The durability of asphalt coatings is influenced by application procedures, adhesion to the substrate, seasonal temperature changes, water absorption, turbulence in the stream flow, and abrasiveness of the bedload. Asphalt is satisfactory where abrasive flows and high salt conditions are not encountered.
10. Asphalt mastic is not a durable coating.
11. Asphalt composition varies widely depending on the source of crude oil. Performance variations of culvert asphalt are attributable to the water absorption and abrasion properties of asphalt and current methods of application.
12. There are several alternative coatings that should be evaluated for use on culverts. These coatings, while more expensive than current culvert coatings, could be cost effective for selected applications, such as on inverts.
13. Many state and AASHTO specifications should be made more specific.

In some severe environments, materials known to be durable can be used in place of coatings or other measures.

The Soil Conservation Service, after a survey of spillways in Iowa, Kansas, Missouri, and Nebraska, drafted the following protective measures for corrugated metal spillways (14):

1. Use asphalt or other approved coatings on all corrugated steel pipe except (a) in temporary installations; (b) where experience in similar soil and moisture conditions in the area indicates a justifiable economic life for uncoated pipe; (c) the soil resistivity exceeds 400 ohm-cm, the pH is 5.0 or greater, and there is no experience in the area that indicates an unusually corrosive condition; or (d) replacement is relatively easy and low cost, such as a small pipe with shallow cover.
2. Do not consider corrugated steel pipes to be watertight. Do emphasize the careful assembly and tightening of bands to produce as tight a pipe as possible.
3. Do not use paved inverts on pipes designed for pressure flow (drop inlets or hooded inlets). If paved inverts are required, design the pipe to assure channel flow.
4. Design pipe grades to avoid ponding of water in a pipe whenever site conditions permit. This includes a positive pipe grade after foundation settlement and a free-draining outlet.
5. Backfill pipes with the least corrosive soil available that meets other backfill requirements. This includes highest resistivity, neutral pH, and freedom from organic matter. As nearly as possible, use the same soil material for all backfill, including undercutting the pipe grade and placing at least 1 ft of backfill beneath the pipe. Free-draining granular materials are usually less corrosive than clayey soils.

Recently, pipe culvert producers have made available corrugated steel with either prime aluminum or a mixture of aluminum and zinc coatings. The aluminized steel has a performance history dating back to the 1950s, when experimental installations of aluminized steel were placed at 21 sites in 7 environments. It has been reported that a second group of Type 2 aluminized pipe was later placed at more than 150 sites. These now have an experience record of 25 years. Performance has been reported to be good, except in salt water, mine water, and sanitary sewage exposures (according to an ARMCO memorandum by Herb Lawson, "Data on Aluminized Steel, Type 2, Corporated Steel Pipe"). It would appear from the data obtained thus far that specification requirements for this material should include limits on chloride and sulfate content, in addition to pH.

Concrete pipes in strongly acid environments have been protected by clay tile set into the invert of the pipe. Protection should be considered when the pH is less than 4.5. In high sulfate areas, as exist in parts of the western United States, protection can be achieved by changing the type of cement and increasing the amount of cement [Table 3 (3)].

When no head walls are used, several northern states require that end sections of concrete culverts be tied together with restraining devices to prevent separation caused by frost action or undermining.

Thin-gauge aluminum pipe is protected by an aluminum-zinc cladding and occasionally with an additional bituminous coating. Adhesion of the asphalt can be a problem. Thicker-gauge aluminum structural plate is made with 5052 alloy not protected by cladding.

Where culverts are subject to abrasive bedloads, asphalt or concrete paving has been used for additional protection. Other methods include using thicker plates in the invert, steel rails welded to the invert, and other special techniques. In extremely abrasive conditions, concrete pipe is occasionally protected by a concrete paving in the invert. Where corrosive conditions are severe, sacrifical thicker wall sections have been used for nearly all types of culverts.

INSPECTION

Detection of structural, hydraulic, or corrosion and abrasion problems when they are the most economical to remedy requires periodic inspections by trained and equipped inspectors. Inspection also provides a basis for updating existing methods for predicting service life.

Culverts achieve much of their economies through the structural use of backfill properties. Structural distress mechanisms are different from those common to bridges. An understanding of the soil-structure interaction as well as the corrosion-abrasion interaction is needed to obtain information from inspection that will be useful for establishing optimum rehabilitation types and timing. Condition rating systems in use vary widely. Development of a common rating system would be a valuable step toward a nationwide basis for predicting the service life of culverts.

A sample inspection form used for an FHWA culvert study in Oregon is shown in Figure 5 (15). In addition to the type of information shown on these forms, a field evaluation of long-span culverts should provide for nonsymmetrical anomalies such as bulges, seam distress, and out-of-original shape. These can be a clue to potential problems with the soil-structure interaction.

It has been recommended that major culverts be inspected at least every 3 years, and more often in known severe corrosive environments (3).

MAINTENANCE AND REPAIR

In addition to routine clearing of debris, which can cause or threaten blockage of flow, and removal of abnormal accumulations of deposited sediment, maintenance of culverts may include major repairs of corrosion and abrasion damage. Techniques employed for metal culverts have included recoating; lining with concrete, cement grout, and plastics; plugging of leaks with expanding bands, grouting, and welding; and insertion of a smaller pipe. Concrete culverts have been repaired by relining with grout; occasionally by removal and replacement of deteriorated concrete; with the insertion of clay or plastic liners; and by applying polymer coatings. The high cost of replacing and repairing long culverts under deep fills justifies an evaluation of repair techniques used in the past. Where they are found to be either ineffective or overly expensive, the development of improved and more economical techniques is warranted.

ESTIMATION OF SERVICE LIFE

Service life will probably continue to be thought of as the years of relatively maintenance-free performance. Methods used to predict the probable service life of a culvert include

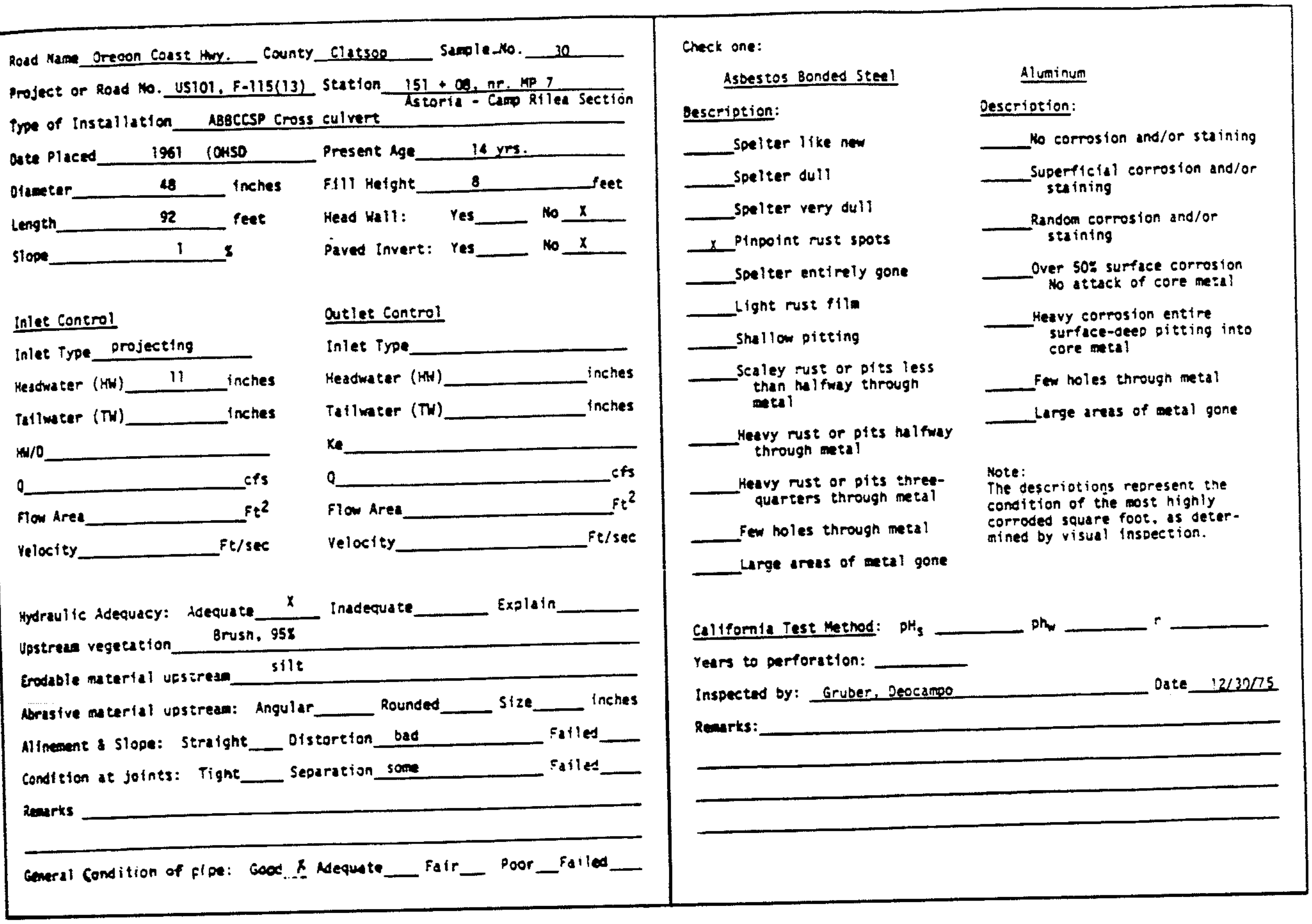
1. Field performance of in-service culverts,
2. Field prototype tests (such as have been conducted by Kentucky, Louisiana, and other states),
3. The performance of materials in other field applications,
4. Laboratory methods, and
5. Analytical methods.

TABLE 3 Guide for Sulfate-Resistant Concrete Pipe and Other Concrete Drainage Structures *(3)*

Water-Soluble Sulfate (SO_4) in Soil Sample (%)	Sulfate (SO_4) in Water Sample (ppm)	Type of Cement	Cement Factor
0-0.2	0-2,000	II	Minimum required by specifications
0.2-0.5	2,000-5,000	V	Minimum required by specifications
		II	7 sacks[a]
0.5-1.5	5,000-15,000	V	Minimum required by specifications
		II	7 sacks[a]
>1.5	>15,000	V	7 sacks[a]

Note: Recommended measures for cement type and factor based on sulfate content of soil and water (California 7-851.3D).

[a] Seven-sack cement = 390 kg of cement per meter of concrete.



Road Name Oregon Coast Hwy. County Clatsop Sample No. 30

Project or Road No. US101, F-115(13) Station 151 + 08, nr. MP 7 Astoria - Camp Rilea Section

Type of Installation ABBCCSP Cross culvert

Date Placed 1961 (OHSD Present Age 14 yrs.

Diameter 48 inches Fill Height 8 feet

Length 92 feet Head Wall: Yes ____ No X

Slope 1 % Paved Invert: Yes ____ No X

Inlet Control

Inlet Type projecting

Headwater (HW) 11 inches

Tailwater (TW) ____ inches

HW/D ____

Q ____ cfs

Flow Area ____ Ft^2

Velocity ____ Ft/sec

Outlet Control

Inlet Type ____

Headwater (HW) ____ inches

Tailwater (TW) ____ inches

Ke ____

Q ____ cfs

Flow Area ____ Ft^2

Velocity ____ Ft/sec

Hydraulic Adequacy: Adequate X Inadequate ____ Explain ____

Upstream vegetation Brush, 95%

Erodable material upstream silt

Abrasive material upstream: Angular ____ Rounded ____ Size ____ inches

Alinement & Slope: Straight ____ Distortion bad Failed ____

Condition at joints: Tight ____ Separation some Failed ____

Remarks ____

General Condition of pipe: Good X Adequate ____ Fair ____ Poor ____ Failed ____

Check one:

Asbestos Bonded Steel

Description:

____ Spelter like new

____ Spelter dull

____ Spelter very dull

x Pinpoint rust spots

____ Spelter entirely gone

____ Light rust film

____ Shallow pitting

____ Scaley rust or pits less than halfway through metal

____ Heavy rust or pits halfway through metal

____ Heavy rust or pits three-quarters through metal

____ Few holes through metal

____ Large areas of metal gone

Aluminum

Description:

____ No corrosion and/or staining

____ Superficial corrosion and/or staining

____ Random corrosion and/or staining

____ Over 50% surface corrosion No attack of core metal

____ Heavy corrosion entire surface-deep pitting into core metal

____ Few holes through metal

____ Large areas of metal gone

Note:
The descriptions represent the condition of the most highly corroded square foot, as determined by visual inspection.

California Test Method: pH_s ____ ph_w ____ r ____

Years to perforation: ____

Inspected by: Gruber, Deocampo Date 12/30/75

Remarks: ____

FIGURE 5 FHWA-Oregon Division culvert pipe inspection report *(15)*.

Current methods of predicting culvert service life are often the result of a combination of one or more of the actions in the list. Highly regionalized pipe durability performance data derived from field performance surveys often reveal a lack of agreement from one region to another, depending on which variables are included as predictors and which other variables are omitted because they have only a small variation in one region, even though they may be important in another region.

Rather than reiterate one or more of the different prediction methods currently in use, a summary of the states' assumed useful culvert life for several types of culverts is shown in Figure 6, derived from the results of a recent national survey by the New York State Department of Transportation (16). This summary, a "lumping" of environmental conditions, soil types, installation methods, and other factors, is intended to indicate that there is great variability in field service conditions and performance experience, and as a result there is a wide range of assumed years of useful culvert life by the states.

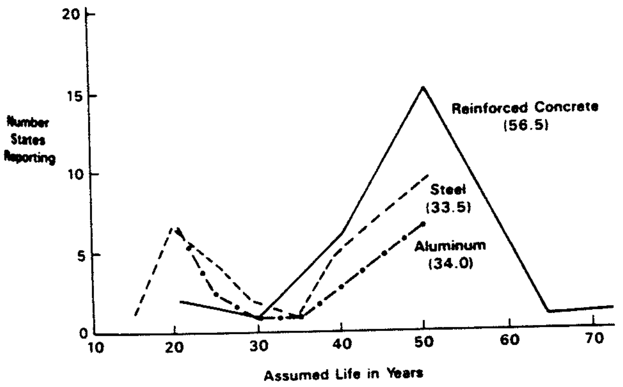


FIGURE 6 Assumed useful life of culverts *(16)*.

Laboratory tests are sometimes useful for determining relative durability, but more often than not they are not directly indicative of field performance, except in the most carefully designed and conducted test programs.

An example of a field prototype study is a continuing study in Louisiana (17). Panel ratings of the culverts at 2-, 4-, and 6-year periods reveal a gradual decline in condition for nearly all the types of metal culverts included in the study, as the data given in Table 4 (17) indicate.

FHWA TECHNICAL ADVISORY

The FHWA first issued a Technical Advisory on corrugated metal pipe durability to its field offices and to the states in March 1978 (5). This was intended to encourage and help the states specify equal-alternate materials for some culvert, underdrain, and storm drain applications.

A revision of the 1978 Technical Advisory was issued by the FHWA Office of Engineering in October 1979 (7). A summary of revised durability criteria is given in Table 2.

TABLE 4 Change in Culvert Condition with Time (*17*)

	Average Rating[a] by Years Exposed		
	2	4	6
Galvanized steel	2.0	2.8[b]	3.2[b]
12-mil coal-tar polymer over galvanized steel	1.6	2.2	2.5[b]
20-mil coal-tar polymer over galvanized steel	1.5	2.3[b]	2.7[b]
10/3-mil polyethylene over galvanized steel	1.3	2.1	2.1[b]
12/5-mil polyethylene over galvanized steel	1.3	2.2[b]	2.2[b]
10/3-mil vinyl over galvanized steel	1.4	1.4	-
Asphalt on galvanized steel	1.4	2.1[b]	2.4[b]
Asbestos-bonded asphalt on galvanized steel	1.3	1.4	1.6
Clad aluminum alloy	2.2	2.0	2.3[b]
Asphalt on clad aluminum alloy	1.4	2.1	2.4
Aluminum alloy structural plate	2.0	2.0	2.4

Note: Data give average rating for 11 sites (pH 5.4 to 7.4) [electrical resistivity (ohm-cm) 92-20,667].

[a] Panel ratings: 1 = excellent, 2 = good, 3 = fair, and 4 = poor.

[b] Perforated at one or more locations where conditions were more severe.

To date there have been no FHWA durability guidelines established for concrete pipe culverts. FHWA continues to encourage the use of alternative materials in drainage design through a program that emphasizes area objectives (according to a 1983 letter from FHWA to ARMCO Steel Corporation). State highway agencies are encouraged to adopt an ongoing value-engineering program. A systematic approach in value-engineering analyses uses life-cycle costing techniques, as appropriate, to reliably obtain the desired function for culvert facility at lowest overall cost.

Based on available culvert performance information and durability criteria as it relates to the development of both the highway system and improvements in culvert materials, the science (art) of predicting the service life of culverts is still in the development stage. Refinements in currently used criteria are needed. However, the relationships established to date, when used with care, may be adequate for specifying equal-alternate products for many design situations.

The high costs of making field performance surveys, both in man-hours and in either overspecifying or underspecifying culvert durability requirements, strongly indicate a need for a detailed study of all known documentation of culvert and culvert material durability performance.

Research recommendations in NCHRP Synthesis of Highway Practice 50 (3) continue to be an important need.

1. The apparent poor correlation among corrosion indicators indicates that the collection of additional data on existing culverts and coatings and the continuation of research in this area are desirable.

2. Transportation agencies with similar environmental conditions should work together to develop improved pipe material selection criteria.

3. Coatings and treatments have been developed to protect culvert pipes. Research is needed to determine the effectiveness of these coatings and treatments, the specific applicability of each, and their economic value.

4. A culvert located under a deep fill or under a highway with high traffic volumes cannot be easily replaced. Research into methods and materials that can be used to salvage in-place culverts would be highly desirable.

5. There should be a continuing search to identify culvert materials that are resistant to corrosion and abrasion under a wide range of conditions and that possess the strength needed to meet structural requirements.

6. A few state transportation agencies have corrosion engineers or specialists on their staffs. Others could benefit from the addition of such specialists, not only to analyze potential or actual corrosion of culverts, but also to assess corrosion of other facilities such as bridge decks and lighting systems. Development of in-house expertise through training programs is a secondary means of enhancing capability.

7. Currently, only a few transportation agencies are engaged in any major research on pipe durability. There are some agencies that believe that a more intensive research effort is desirable; however, there is some question as to how to organize the research. One approach might be a major study with nationwide support by all transportation agencies. A second approach would combine the efforts and funding of transportation agencies that have common problems. Individual agencies should continue to document conditions at new pipe installations and to perform in-depth examinations when existing pipes are removed or replaced.

With a new national emphasis on rehabilitation and replacement of bridges, and a corresponding increase in the use of large culverts, it is hoped that engineers will continue to make progress on durability, inspection, and cost-effectiveness criteria for highway culverts in the foreseeable future.

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Publication of this paper sponsored by Committee on Culverts and Hydraulic Structures.

Durability of Polymer-Coated Corrugated Steel Pipe

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ABSTRACT

Corrugated steel pipe has been in use for nearly 90 years. Various coatings have been employed to increase its service life and to provide durability in severe environments. Methods have been developed to precoat the culvert stock with a polymer material, either as a liquid dispersion or as a thermoplastic film applied by lamination, before fabrication. The coating materials selected have proved to be easy and economical to use in the fabrication process and can pass stringent tests and specifications as required by AASHTO and ASTM. Test locations and actual field service installations have established the validity of the concept of coating galvanized culvert stock with polymer material. Actual conditions of use in severe environments, which range from acidic to alkaline soils and effluents, abrasive bedloads, extremes of temperature, and varying conditions of wetting, have demonstrated the durability of polymer-coated steel culvert pipe. In this paper the reasons for the development of the polymer-coated corrugated steel pipe are presented, the manufacturing processes used to make and fabricate the coated sheet and corrugated culvert pipe are described, the tests that the coated material must pass to be acceptable are explained, and data on the actual field performance of installed polymer-coated culverts, which demonstrates its performance in a variety of severe service environments, are presented.

Corrugated steel pipe has been used for drainage applications since 1896. Continuing effort has been made in the years since then to improve the performance of corrugated steel pipe to ensure its durability and efficiency.

In the early 1900s iron and steel culvert sheets were hot-dip galvanized to improve corrosion resistance. Around 1925 the use of an asphalt coating applied over the zinc was developed to reduce corrosion potential. This remained the state of the art until, in the early 1960s, trial installations of culvert pipe made of a chromium grade stainless-steel sheet were placed in highly aggressive acid mine runoff areas in Ohio and Pennsylvania. Coal tar enamel, an effective and often used coating for gas pipelines, was also tried. Results indicated that coal tar enamel and stainless steel can provide extended service life. However, material costs are expensive, often doubling the cost of conventional zinc-coated pipe, and are not necessary for most corrugated steel pipe installations not subject to such severe environments under typical conditions of use. For moderate to severe environments, an asphalt coating over mill-galvanized steel remained the economical choice.

The need for an even better protective system was recognized that would provide enhanced durability and service life. A polymer coating applied under controlled mill conditions would provide such a system. Such a coating would have to be easy and cost effective to apply with consistent high quality. Specific requirements would be good adherance to the zinc surface under a full range of exposure temperatures; good impact properties throughout such a temperature range; good abrasion resistance under a range of typical bedload conditions; superior corrosion protection over the full range and concentrations of acid and alkalai soils and effluents