Kentucky Culvert Study: An Engineering Review of Policies and Practices Related to Procurement of Culvert and Sewer Pipe

Byrd, Tallamy, MacDonald and Lewis
KENTUCKY CULVERT STUDY

AN ENGINEERING REVIEW OF POLICIES AND PRACTICES
RELATED TO PROCUREMENT OF CULVERT AND SEWER PIPE

Contract CA 00738

Byrd, Tallamy, MacDonald and Lewis
A Division of Wilbur Smith and Associates
Falls Church, Virginia
June, 1979
June 18, 1979

Mr. Calvin G. Grayson
Secretary of Transportation
Department of Transportation
Frankfort, Kentucky 40601

Dear Mr. Grayson:

Transmitted herewith is our final report on the engineering review of policies and practices related to the procurement of culvert and sewer pipe for the Kentucky Department of Transportation.

Our findings are based on a review of past and ongoing nationwide research and testing programs, practices in other states and Kentucky's own considerable activities in this field.

From this data, we have prepared a series of recommendations for optional culvert pipe selections for the range of conditions of Kentucky drainage water. These recommendations are reflected in the attached proposed Policy Statement for promulgation by the Kentucky Department of Transportation.

Appreciation is expressed to William B. Drake and members of the Research Staff for their assistance and valuable support during this program.

Sincerely,

Lloyd G. Byrd

LGB:jlk
Enclosures
Policy Statement

Department of Transportation
Frankfort, Kentucky

Office of the Secretary

Subject: Culvert Pipe and Entrance Pipe

This official order supersedes and cancels Official Order No. 83154 titled "Culvert Pipe and Entrance Pipe" dated 6 July 1977.

It is hereby ordered that the following policies and procedures will govern the section of culvert and entrance pipe.

a. Structural and hydraulic requirements are outlined in the Department's Design and Drainage Manuals.

b. Within normal structural and hydraulic restrictions the pipe selection options will be based upon a site-by-site examination of the current and potential pH of the runoff the pipe is expected to carry during design life. Instructions for determining the potential pH will be issued by the Department of Design which will monitor and approve the findings at each site.

c. These selection criteria apply:
   (1) to both Federal-aid and state-funded projects
   (2) to new construction and maintenance
   (3) to both contract and force account work.
## Acceptable Alternative Pipe Selection Criteria

<table>
<thead>
<tr>
<th>pH Range</th>
<th>Permissible Options</th>
<th>Pipe Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>greater than 6</td>
<td>a. Plain Galvanized Corrugated Steel Pipe</td>
<td>AASHTO M36 &amp; M167</td>
</tr>
<tr>
<td></td>
<td>b. Reinforced Concrete Pipe</td>
<td>AASHTO M170</td>
</tr>
<tr>
<td></td>
<td>c. *Aluminum Corrugated Pipe</td>
<td>AASHTO M196 &amp; M219</td>
</tr>
<tr>
<td></td>
<td>*In highly abrasive areas eliminate this option</td>
<td></td>
</tr>
<tr>
<td>greater than 4 and less than</td>
<td>a. Bituminous coated and paved corrugated galvanized</td>
<td>AASHTO M36 &amp; M190</td>
</tr>
<tr>
<td>or equal to 6</td>
<td>steel pipe</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b. Reinforced concrete pipe</td>
<td>AASHTO M170</td>
</tr>
<tr>
<td></td>
<td>c. Bituminous coated and paved aluminum corrugated pipe</td>
<td>AASHTO M196 &amp; M190</td>
</tr>
<tr>
<td>less than or equal to 4</td>
<td>a. Asbestos-Bonded, Bituminous coated and paved</td>
<td>FH WW-P-405B Section 3.6.7</td>
</tr>
<tr>
<td></td>
<td>galvanized corrugated steel pipe</td>
<td>Coating G &amp; KyDOT Special</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provision No. 7(76)</td>
</tr>
<tr>
<td></td>
<td>b. Reinforced Concrete Pipe with extra protection</td>
<td>AASHTO M170 &amp; KyDOT Special</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provision No. 14 (76), Type V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cement (ASTM Spec. C150-72)</td>
</tr>
<tr>
<td></td>
<td>c. Vitrified Clay Extra Strength Pipe</td>
<td>AASHTO M65</td>
</tr>
<tr>
<td></td>
<td>d. Stainless Steel Corrugated Pipe</td>
<td>ASTM A409-72</td>
</tr>
<tr>
<td></td>
<td>e. Vitrified Clay Lined Reinforced Concrete Pipe</td>
<td>AASHTO M170 &amp; ASTM C479-72</td>
</tr>
<tr>
<td></td>
<td>f. Cast Iron Pipe</td>
<td>AASHTO M64</td>
</tr>
</tbody>
</table>

Signed and Approved by me this ___ day of _____, 1979.

Secretary
TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Page</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Page</td>
</tr>
<tr>
<td></td>
<td>iii</td>
</tr>
<tr>
<td>I.</td>
<td>1</td>
</tr>
<tr>
<td>II.</td>
<td>2</td>
</tr>
<tr>
<td>III.</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>6</td>
</tr>
<tr>
<td>IV.</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>V.</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>23</td>
</tr>
<tr>
<td>APPENDICES</td>
<td></td>
</tr>
<tr>
<td>Appendix A.</td>
<td>Questionnaire submitted to six state highway agencies.</td>
</tr>
<tr>
<td>Appendix B.</td>
<td>Comparative Policies and Practices on Selection of Pipe.</td>
</tr>
<tr>
<td>Appendix C.</td>
<td>HRIS Abstract</td>
</tr>
<tr>
<td>Appendix D.</td>
<td>KyDOT Research Activities on Alternate Culvert Pipe Materials</td>
</tr>
<tr>
<td>REFERENCES</td>
<td></td>
</tr>
</tbody>
</table>

LIST OF TABLES

1. Pipe Material Based on pH of Drainage Water 14
2. Pipe Selection Option 21
EXECUTIVE SUMMARY

Objectives

This study was undertaken to provide the Kentucky Department of Transportation (KyDOT) with 1) information concerning the present state-of-the-art in the selection of culvert pipes with reference to the problem of drainage water from coal mines, shales and other excavations which may be highly acidic; and 2) recommendations on alternative materials and/or special treatments for pipes in areas of acid drain water.

Methodology

The study consisted of a review of the literature from selected highway agencies including Kentucky, a review of culvert pipe selection practices in other states and discussions with persons knowledgeable about pipe materials.

Findings

The pH of drainage water is the dominant factor affecting pipe performance in Kentucky. Three breakpoints in the pH ranges of drainage water can be used to define environmental conditions at drainage sites. Several alternative pipe materials and coatings are suitable for each pH range.

Recommendations

Based upon the study data and findings, a series of recommendations have been developed which can be used by KyDOT in a policy for selection of materials and/or special treatments for pipe culverts for each set of environmental conditions encountered in Kentucky.
Recommendations relating to environmental classifications and pipe specifications are summarized in the following table.

**PIPE SELECTION OPTIONS**

<table>
<thead>
<tr>
<th>pH Range</th>
<th>Permissible Options</th>
<th>Pipe Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>greater than 6</td>
<td>a. Plain Galvanized Corrugated Steel Pipe</td>
<td>AASHTO M36 &amp; M167</td>
</tr>
<tr>
<td></td>
<td>b. Reinforced Concrete Pipe</td>
<td>AASHTO M170</td>
</tr>
<tr>
<td></td>
<td>c. *Aluminum Corrugated Pipe</td>
<td>AASHTO M196 &amp; M219</td>
</tr>
<tr>
<td></td>
<td>*In highly abrasive areas eliminate this option</td>
<td></td>
</tr>
<tr>
<td>greater than 4 and less than or equal to 6</td>
<td>a. Bituminous coated and paved corrugated galvanized steel pipe</td>
<td>AASHTO M36 &amp; M190</td>
</tr>
<tr>
<td></td>
<td>b. Reinforced concrete pipe</td>
<td>AASHTO M170</td>
</tr>
<tr>
<td></td>
<td>c. Bituminous coated and paved aluminum corrugated pipe</td>
<td>AASHTO M196 &amp; M190</td>
</tr>
<tr>
<td>less than or equal to 4</td>
<td>a. Asbestos-Bonded, Bituminous coated and paved galvanized corrugated steel pipe</td>
<td>FH WW-P-405B Section 3.6.7 Coating G &amp; KyDOT Special Provision No. 7(76)</td>
</tr>
<tr>
<td></td>
<td>b. Reinforced Concrete Pipe with extra protection</td>
<td>AASHTO M170 &amp; KyDOT Special Provision No. 14 (76), Type V Cement (ASTM Spec. C150-72)</td>
</tr>
<tr>
<td></td>
<td>c. Vitrified Clay Extra Strength Pipe</td>
<td>AASHTO M65</td>
</tr>
<tr>
<td></td>
<td>d. Stainless Steel Corrugated Pipe</td>
<td>ASTM A409-72</td>
</tr>
<tr>
<td></td>
<td>e. Vitrified Clay Lined Reinforced Concrete Pipe</td>
<td>AASHTO M170 &amp; ASTM C479-72</td>
</tr>
<tr>
<td></td>
<td>f. Cast Iron Pipe</td>
<td>AASHTO M64</td>
</tr>
</tbody>
</table>
It is recommended that KyDOT adopt a site-by-site inspection procedure to determine the probable potential pH of the water rather than a blanket area policy.

It is further recommended that KyDOT include a continuing culvert inspection program and a training program for department maintenance personnel responsible for handling and inspecting culvert pipe.

The specifications recommended in this report should apply to new construction, betterments, and maintenance activities, whether performed by contract or force account. In stockpiling pipe for force account work, the costs and procedures for transporting, handling and placing by maintenance employees should be considered along with the price of the pipe, before a least-cost selection is made.
I. INTRODUCTION

The Kentucky Department of Transportation (KyDOT) over the years has issued a series of policy statements and has revised its design and other technical manuals on the use of various types of culvert pipes for protection against corrosion and abrasion. Changes have occurred as knowledge of the causes of pipe deterioration has been gained; as new pipe, protective materials and technology have been developed and reached the market; and as engineering personnel have changed, bringing differing education, experience and judgment to the Department.

In order to determine the extent and kind of revision presently needed in its policies, KyDOT retained Byrd, Tallany, MacDonald and Lewis (BTML) (Contract No. CA 00738) to make an engineering review of policies and practices related to the durability of pipe used in highway construction and to recommend modifications and changes where warranted.
II. OBJECTIVES

The objectives of the study were twofold:

- Provide KyDOT with information concerning the present state-of-the-art in the selection of culvert pipes under environmental conditions similar to Kentucky's (which is primarily a problem of drainage water from coal mines, shales and other excavations which may be highly acidic) and

- Provide recommendations on alternative materials and/or special treatments for pipes for the environmental conditions.
III. METHODOLOGY

The review of the state-of-the-art of protecting culvert pipes from hostile environmental elements included:

- a literature search,
- the review of culvert pipe selection practices in six states with geologic and environmental conditions somewhat similar to those found in Kentucky,
- discussions with KyDOT personnel,
- a review of KyDOT files on the subject,
- discussions with Federal Highway Administration personnel,
- discussions with personnel representing two trade associations: the American Concrete Pipe Association and the American Iron and Steel Institute.

Literature Search

The first step in the literature search was a review of a Highway Research Information Service (HRIS) printout of research projects. The HRIS printout included three sets of key words: pipe and coatings; pipe durability; and pipe and drainage. There were a total of ninety-nine abstracts, of which 19 were found to be relevant. Of these, five were used as background information in the report (6, 10, 13, 14, 25). The remaining 14 dealt with the following subjects:

- Five discussed polymer concretes which at this time are still in an experimental stage.
- Four dealt with plastic pipe, which are used only for smaller applications due to low material strength.
- Five covered the reactions of soil pH on the pipe. One report, however, (25) was used in the study.
- One abstract was a later version of reference (7), which related to culvert pipe subjected to drainage waters in the pH range 6.2-9.0.

A listing of the 19 abstracts can be found in Appendix C.

A review of Federal Highway Administration (FHWA) and Transportation Research Board (TRB) documents also was made. Publications of the American Association of State Highway and Transportation Officials (AASHTO) have been used for reference.

The relevant material was examined in the BTML library and other libraries, including the Transportation Research Board library.

**Review of Practices in Six States**

A questionnaire (Appendix A) was developed seeking information on policy, practices and specifications for pipe culverts in an acid water environment in six states: Illinois, Ohio, Pennsylvania, Tennessee, Virginia and West Virginia. Responses were received from all states except Tennessee (Appendix B). Reports of problems encountered and practices, especially in Ohio, Pennsylvania, and West Virginia, were most helpful in arriving at BTML recommendations for Kentucky, which are detailed in Section V of this report.

**Discussions with KyDOT Personnel**

Several conferences were held with KyDOT personnel. Information was obtained on pipe policies and practices in Kentucky which provided insights
into Kentucky's problems and needs. Information obtained also included material and reports on Kentucky's long term research effort at Morton's Gap.

**Review of KyDOT Files**

By far the greatest source of information was found to be in the library of the KyDOT Research Laboratory. Not only were most of the papers and reports that were found elsewhere available in the Research Library, but also all the information and data on Kentucky's own voluminous research. Eleven of these reports are listed in the References. A summary of the studies conducted on the durability of various types of culvert material by Kentucky over the past 30 years is found in Appendix D.

A recent review by KyDOT of the practices and experience of the 48 contiguous states on pipe durability is included as part of Appendix B, "Comparative Policies and Practices on Selection of Pipe."

**Discussions with FHWA Personnel**

FHWA has provided durability guidelines for the design of corrugated metal pipe but is careful to point out that these are only guidelines and that neither FHWA nor AASHTO provide guidance on how to estimate service life relative to the various environmental factors which come into play during the lifetime of a drainage structure (23).

The only research project currently underway by FHWA's Office of Research and Development is entitled "Evaluation of Highway Culvert Coating Performance"(30). The major emphasis of this report is an evaluation of metal pipe culvert coating performance.
Discussions with Trade Associations and Manufacturers

Conferences were held with representatives of two trade associations, the American Concrete Pipe Association and the American Iron and Steel Institute, as well as the Armco Steel Pipe Company. Relevant background information and several technical publications, not available in the general literature sources on this subject were made available.
IV. FINDINGS

In order to carry on the study, it was necessary to look at the factors that affect the durability and service life of culvert pipe in Kentucky and review practices and experience in other jurisdictions to make recommendations in Kentucky.

Many factors affect durability and service life. As stated by FHWA, "The complex combination makes it impossible at this time to identify and quantify all these variables" (23).

"Some of the factors which affect the service life of various culvert materials are pH, resistivity, chemical analysis, hardness, saturation, velocity, and sediments in or of the stream water, as well as resistivity of the surrounding soil at its natural moisture content. Specific values for the various factors at a particular culvert installation may be expected to vary considerably and the values would be largely dependent upon antecedent and current conditions at the site at the time of testing. Various studies that have been undertaken for the purpose of correlating durability with site variables have been relatively unreliable and unsuccessful. The primary difficulty in attempting to establish such a correlation is determination of a mean or average value for each of the site variables." (4)

The relationship among these independent variables has never been significantly determined. A computer multiple regression analysis in Ohio (16) developed only insignificant correlation except for pH and age. A study (15) of similar nature in Michigan, but confined primarily to soil resistivity, also developed little correlation.

Major Environmental Conditions Affecting Pipes

Of the many factors affecting durability and service life of pipes (discussed above) and based on studies that have been made throughout the United States, only three factors appear to have great significance.

- pH of water carried by pipe
"A pH value of 7.0 is neutral; values of less than 7.0 are acid; values of more than 7.0 are alkaline. For culvert purposes, soils or water having a pH of 5.5 or less are strongly acid, and those of 8.5 or more are strongly alkaline. For example, a solution with a pH of 4 is 10 times more acid than one with a pH of 5, or 100 times as acid as one with a pH of 6."(22)

- resistivity of surrounding soil
  A factor (the reciprocal of electrical conductivity) used for estimating the corrosivity of a soil to metals.
- abrasion from rocks and sand during periods of extremely rapid flow.

**pH as Independent Variable** - Acid water stems from two natural sources, mineral and organic. Mineral acidity comes from sulfurous wells and springs, and drainage from coal mines. These sources contain dissolved sulfur and iron sulfide which, on exposure to air and sunlight, react with oxygen to form sulfurous and sulfuric acids. Mineral acidity as strong as pH 2.3 has been encountered. Even stronger acidity may result from evaporation of water during dry weather, since sulfuric acid is non-evaporating.

Organic acidity arises from decay of vegetation usually found in swampy land and barnyards. The highest organic acidity of this type would not produce a pH less than 4.0.

Alkalinity in water is caused by strong alkali-forming mineral and from limed and fertilized fields.

Kentucky uses only present and potential pH values as the sole environmental factor to determine pipe selection because the major problem is the acidity of drainage waters from coal mines, shale and other excavations.

Virginia also is reported to have "examined several chemical parameters but relies largely on pH as the corrosion potential index under a variety of exposures, including acid mine waste water, brackish tidewater water; and swamp, pasture, and hillside drainage."(18)
There has been no indication of a problem in Kentucky from the external factor of soil resistivity. It is a problem where acid mine tailings have been used as a backfill over pipe and in western states where alkaline soil may attack the pipe from the exterior.

Serious abrasions of coated pipes, corrugated metal and concrete pipes is of concern in Kentucky, but in most of the state, terrain and proper design has maintained the water velocity below that which causes abrasion.

With the pH value determined to be the control factor (or independent variable) in Kentucky, it was necessary to determine recommended breakpoints in the pH scale for use in selection of various kinds of pipes.

**Selection of Breakpoints in the pH Scale** - Breakpoints in the pH scale must be established to determine the points where added protection against corrosion should be made to assist in specifying pipe materials. Authorities agree that the degree of protection against corrosion of pipes should vary with the pH to take advantage of pipe prices; the more expensive pipes are required at extreme ends of the pH scale.

No available data pinpoints precisely where the breakpoints should be made in a scale. An examination of the breakpoints in states with problems similar to Kentucky's (Ohio, Pennsylvania, Virginia and West Virginia) indicate a break on the acidic side between pH of 3.5 and 4.5 and another between 5.0 and 6.0.

Another example of a breakpoint, in a report on durability considerations by Krizek, et al (14) reported that in predicting the rate of culvert corrosion "...below a pH value of approximately 4, a high rate of metal loss will occur, and above a pH of 4, a metal loss may or may not occur."
Kentucky is not, as some states are, confronted with water on the alkaline side of the pH scale so no provision need be made beyond the break at pH 6.0.

Culvert Pipe Selection Practices

Background data indicates that the selection of pipe materials involves three principal types: steel, aluminum and concrete (22). Further, it is known that as the environment becomes more hostile, there is need for greater protection of that material. Since this study is concerned only with acid drainage water, the type of material selection is dependent on pH (with the understanding that this discussion concerns only the acid drainage water and not other influences, such as structural and hydraulic considerations, installation methods, maintenance factors, availability and the economics of the situation, such as the cost of various types).

Other factors affecting the pH of the water within a culvert are the rate of flow (flowing vs. standing water), ability of pH of water to remain in corrugations; and the drying factor of acidic water remaining in corrugations with resulting increase in acidic concentration.

Three pH ranges for specifying pipe have been used by agencies addressing the pipe durability problem. The pipe materials or protection required to withstand corrosion under each range are discussed under: mildly acidic, acidic and extremely acidic environments. All pipe selections listed below are used with a generally accepted level of risk.

Mildly Acidic Environment (greater than 6 pH) - In the mildly acidic environment, plain corrugated steel pipe (with galvanizing), reinforced concrete pipe and aluminum corrugated pipe may be used.
Acid Environment (greater than 4 pH and less than or equal to 6 pH) -
Additional protection of two of the three basic materials for pipe is
used as the water acidity becomes stronger.

The steel and aluminum pipe require bituminous coating and paved
inverts to extend the service life of the pipe.

The reinforced concrete pipe is still appropriate in this pH range.

Extremely Acid Environment (pH equal to or less than 4) - In this
environment, increasing protection is used for the desired service
life of the pipe. This is accomplished in one of the following ways:

- Concrete pipe requires special protection to provide an accep-
table risk level for adequate service life.
- Steel needs additional protection over that in the class just
discussed. Asbestos-bonding is recommended for the bitumi-
nous coated and paved galvanized corrugated steel pipe.
- Aluminum can no longer be used because of the effect of the
  acidity on the material.

Experience has shown that at this pH range concrete is seriously at-
tacked by the acid water. To compensate for this a sacrificial coating
(additional thickness) has been used to add to the service life of the pipe
as well as bridge piers.

The following pipe materials have also been used even though they are
not of the three principle types discussed above. They were not included
due to strength, cost and/or size considerations of the pipe material.

- Vitrified clay (extra strength) pipe may be used in this acid
  environment, although there are structural factors which must
  be considered if this option is chosen.
- Vitrified clay is also used as a liner for reinforced concrete pipe to provide protection.
- It is possible to use stainless steel corrugated pipe in this environment.
- Cast iron pipe may also be used.

Other alternative materials such as epoxy-lined reinforced concrete pipe are used in other states (but are not recommended for standard use at this time due to limited field test data).

Results of the State-of-the-Art Review

The review of the state-of-the-art in pipe selection practices focused on those states which have problems and conditions similar to Kentucky's. A common factor among them is drainage water from coal mines, shales and other excavations which may be acidic.

The number of states on which the analysis is based may appear to be relatively small in number. The lack of data is due to the fact that the problem of acidity is limited to a comparatively small number of states and/or because little research exists on the subject.

Some examples of studies by states in the general area of pipe durability but not related to acid conditions are:

- Utah's soil pHs are in the alkaline range and the corrosion was mainly a problem on the exterior of the pipe, rather than the interior (25).
- New York has conducted studies and research (7) but they deal with pH values of 6.0 and above.
- Louisiana has reported field and laboratory experiments (13) but their report deals with situations other than a high pH value.
Based on information available, Table 1 lists the type of pipes required for carrying acid water as reported by several states.

In the Table, states responding to the questionnaire (see Appendix A) are listed as well as information on other state practices obtained through the literature search and conferences with governmental and industry representatives. A final column lists a proposed pipe schedule for Kentucky.

In reading this table, it should be kept in mind that the pH value of 7 is neutral, neither acid nor alkaline.

As can be seen from the Table, recommendations for Kentucky are comparable with the practices of other states. In reviewing the information in the Table, it should be noted that the pH ranges for various acidic conditions vary from state to state.

For more detailed information concerning data from the individual states, see Appendix B.
<table>
<thead>
<tr>
<th>Type of Pipe Material</th>
<th>pH Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain Galvanized Corrugated Steel Pipe</td>
<td>Ohio 5.0-8.0 Pennsylvania 3.5 or above Virginia All N/A Other State Practices High acid to 8.0, Alabama Acid Area Kansas BTML Proposal for Kentucky Greater than 6.0</td>
</tr>
<tr>
<td>Reinforced Concrete Pipe Type II水泥 cement in high acid areas</td>
<td>4.0-9.5 3.5 or above 4.0-9.0 N/A 4.0-8.0 Indiana 6.5-8.5 Alabama 4.5-8.0 New Jersey Greater than 6.0</td>
</tr>
<tr>
<td>Aluminum Corrugated Pipe</td>
<td>* 5.0-8.0 4.0-9.0 * 4.0-8.0 Indiana 6.5-8.5 Alabama 4.5-8.0 New Jersey Greater than 6.0</td>
</tr>
<tr>
<td>Bituminous Coated and Paved Corrugated Galvanized Steel Pipe</td>
<td>4.0-9.5 5.0 or less greater than 8.0 4.0-9.0 N/A Acid areas Indiana 4.5-8.5 Alabama Greater than 4.0 thru 6.0</td>
</tr>
<tr>
<td>Bituminous Coated and Paved Aluminum Corrugated Pipe</td>
<td>* 5.0 or less 4.0-9.0 * 4.5-6.5 Alabama Greater than 4.0 thru 6.0</td>
</tr>
<tr>
<td>Asbestos Bonded Bituminous Coated and Paved Galvanized Corrugated Steel Pipe</td>
<td>4.0 or less 9.5 or greater * * N/A Less than 5.0 Greater than 9.0 Washington 4.0 or less</td>
</tr>
<tr>
<td>Reinforced Concrete Pipe with Extra Protection</td>
<td>* * * * 4.0 or less</td>
</tr>
<tr>
<td>Vitrified Clay Extra Strength Pipe</td>
<td>All conditions 3.5 or less * 4.5 or less 8.3 or above Acid conditions Indiana Less than 4.5 4.0 or less</td>
</tr>
<tr>
<td>Stainless Steel Corrugated Pipe</td>
<td>4.0 or less 9.5 or above 3.5 or less 4.0-9.0 4.5 or less 8.3 or above 4.0 or less</td>
</tr>
<tr>
<td>Vitrified Clay Lined Reinforced Concrete Pipe</td>
<td>4.0 or less 9.5 or above 3.5 or less * 4.5 or less 8.3 or above 4.0 or less</td>
</tr>
<tr>
<td>Cast Iron Pipe</td>
<td>* * * N/A 4.0 or less</td>
</tr>
<tr>
<td>Coal Tar Epoxy Lined Reinforced Concrete Pipe</td>
<td>4.0 or less 3.5 or less * *</td>
</tr>
</tbody>
</table>

*State specifications do not address this type of pipe

N/A=Information not available
V. RECOMMENDATIONS

Based upon the review of background data and findings, a series of recommendations has been developed which can be used by KyDOT to promulgate a comprehensive statement of policy for use in selection of alternate materials and/or special treatments for pipe culverts for each set of environmental conditions encountered within Kentucky.

These recommendations address, specifically, breakpoints for three environmental classifications for acidic water, pipe specifications for each, and a series of procedures the state should implement regarding site analysis, pipe maintenance, personnel training, and several considerations relating to the application of these recommendations.

Site Analysis Policy

It is recommended that Kentucky adopt a site-by-site inspection policy to determine the probable potential pH of the water rather than relying on a blanket area policy, such as designated acid counties, presently used for the purpose. The reason for this recommendation follows:

- If the area basis were followed, more costly pipe might have to be installed in some instances. This practice might not be economically justified because there may be many locations in the acid counties where extreme acid runoff could not occur. For example, there are culvert locations near ridge lines which would never be exposed to low acid effluent, which are not underlain by potential acid forming shales and other acid types of strata. Cheaper type pipes would be adequate in these and other situations where no potential acid water is likely.
On the other hand, even in non-acid counties acid conditions could occur because of outcroppings or other types of exposure of acidic geological formations.

- The site-by-site inspection could be conducted at marginal increase in cost over that incurred in the conduct of situation surveys (engineering evaluations) normally required for hydraulic and structural designs.

- A site-by-site inspection would permit a detailed engineering analysis of each site to determine the potential pH of the water. Measuring the pH of the current runoff should be but one factor in the determination since the pH at any given time is unstable, depending upon the season of the year, recent rainfall, current runoff, ground water supply, and exposure of acid rock strata.

- The inspection would permit a geological analysis of the underlying terrain in the drainage area to determine if any natural changes in the terrain are likely to expose acid-causing materials.

- The inspection would permit an analysis of the potential and probable land use in the drainage area (strip mining, deep pit mining, other construction or land use projects that may expose acid producing materials).

From this inspection information, a sound engineering judgment can be made of the potential acidity (extremely acid, acid or mildly acid) of the effluent during the design life of the highway project.

**Environmental Classifications**

The following breakpoints in the pH scale are recommended to designate variations in acidic conditions of drainage water in Kentucky:
greater than 6 pH (mildly acidic environment)
greater than 4 and less than or equal to 6 pH (acid environment)
less than or equal to 4 pH (extremely acidic environment).

Pipe Specifications

The following optional pipe materials are recommended based on this study's findings. All optional materials are equally acceptable for the proposed environmental classifications.

Optional Materials for pH of Greater than 6 (Mild acid through neutral environments) - No upper limit was placed on this range of pH since there is no evidence that alkaline water of greater than pH 7.5 is likely to be found in Kentucky. In this pH range, acidity and alkalinity have little corrosive effect on pipes. Protection must, however, be provided against normal rusting of iron and steel. While many other pipe materials may be non-corrosive in this range, only the following appear to be economically and structurally viable.

- Plain galvanized corrugated steel pipe (AASHTO M36 & M167)
- Reinforced concrete pipe (AASHTO M170)
- Corrugated aluminum pipe (AASHTO M196 & M219)

In highly abrasive areas, the corrugated aluminum pipe should be eliminated because of the vulnerability of aluminum to this kind of wear.

Optional Materials for pH of Greater than 4 and Less Than or Equal to 6 (Acid environment) - In this acidic range, evidence from studies and the practices of various highway agencies indicate that metal pipe
needs some degree of protection against corrosion. It is obvious that pipe which will give adequate service in extreme acid environments would also serve well in this higher pH range but would not be economically competitive with pipes of less protection. For that reason, for culvert pipe material in this range, the following alternates are recommended:

- Bituminous coated and paved galvanized corrugated steel pipe (AASHTO M36 & M190)
- Reinforced concrete pipe (AASHTO M170)
- Bituminous coated and paved aluminum corrugated metal pipe (AASHTO M196 & M190)

Optional Materials for pH of equal to or less than 4 (Extreme acid environment) - Although many studies and tests have been undertaken, both in the laboratory and field throughout the United States, none have obtained data conclusive enough to predict accurately the life of pipe under controlled or uncontrolled conditions. These studies also do not indicate that any specific type of pipe is apt to be more economical than any other selection under the same set of conditions. Enough information exists from studies, tests, and practices of various agencies to identify the types of pipe that should give adequate and comparable service in extreme acid environments. The pipe material options recommended for this range are:

- Asbestos-bonded bituminous coated and paved invert corrugated steel pipe (FH WW-P-405B).
- Reinforced concrete pipe with sacrificial concrete (AASHTO M170 & KyDOT Special Provision No. 14(76)).
- Extra strength vitrified clay pipe (AASHTO M65).
- Stainless steel corrugated metal pipe (AASHTO A409-72).
- Cast iron pipe (AASHTO M64).
Other Considerations

Sacrificial Concrete. For reinforced concrete pipe in the extreme acid environment of pH less than or equal to 4, additional sacrificial concrete should be required between the inner surfaces of the pipe and the reinforcing steel. (KyDOT Special Provision No. 14 (76).)

Coated and Lined Pipes. Concrete and metal pipes lined with vitrified clay tile have been used successfully. However, their success depends to a great degree upon the skill and craftsmanship with which the coating materials are applied as well as their placement in the field. Because of this problem, and because these coated and lined pipes are not likely to be economically competitive, they are not recommended for inclusion on a standard list of options in Kentucky at this time. They should be kept in mind, however, for experimental testing where the situation warrants.

Concrete Pipe Aggregates. It has been Kentucky's experience that the use of siliceous aggregates in culvert pipes in acid environments makes them less prone to etching and deterioration than calcareous aggregates. This has been the finding of most other state agencies using reinforced concrete pipe for culverts. One study by Kienow and Pomeroy of California for the U.S. Environmental Protection Agency (12) indicates that calcareous aggregate stands up better in a highly acid environment when used for sewer pipes than do granitic aggregates. This is the only evidence contrary to that found by most agencies. For the foregoing reasons, it is recommended that Kentucky continue to use siliceous aggregates in reinforced concrete pipe for extreme acidic environments.
Polymer Coatings. Polymer coatings, which include polymer-impregnated concrete, polymer penetrants and sealants for both metal and concrete surfaces, have shown evidence (22)(23) that these coatings have increased life expectancy. It is recommended that these developments be monitored for their potential.

Structural and Hydraulic Considerations. Normal structural and hydraulic considerations should, of course, take priority in determining the size and types of culverts for a given location. Within these structural and hydraulic constraints the options permitted by this recommended policy on pipe selections for durability should pertain.

Summary of Pipe Specifications - BTML recommends to the Kentucky Department of Transportation that its policy and all references thereto in technical manuals be revised to reflect the culvert pipe selection options and specifications for each of the three environmental conditions presented in Table 2.

Additionally, Kentucky should continue its practice, which is the practice of most other state highway agencies, of using the latest specifications of the American Association of State Highway and Transportation Officials (AASHTO), FHWA and American Society for Testing and Materials (ASTM). These specifications are standard, usually developed by those who are going to use them (such as the state highway agencies in AASHTO) and therefore represent the best practice.

Maintenance Procedures

BTML recommends that KyDOT modify its procedures to include consideration of a continuing culvert inspection program and also training program for department personnel involved in handling and inspecting culvert pipe.
<table>
<thead>
<tr>
<th>pH Range</th>
<th>Permissible Options</th>
<th>Pipe Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>greater than 6</td>
<td>a. Plain Galvanized Corrugated Steel Pipe</td>
<td>AASHTO M36 &amp; M167</td>
</tr>
<tr>
<td></td>
<td>b. Reinforced Concrete Pipe</td>
<td>AASHTO M170</td>
</tr>
<tr>
<td></td>
<td>c. *Aluminum Corrugated Pipe</td>
<td>AASHTO M196 &amp; M219</td>
</tr>
<tr>
<td></td>
<td>*In highly abrasive areas eliminate this option</td>
<td></td>
</tr>
<tr>
<td>greater than 4 and less than</td>
<td>a. Bituminous coated and paved corrugated galvanized steel pipe</td>
<td>AASHTO M36 &amp; M190</td>
</tr>
<tr>
<td>or equal to 6</td>
<td>b. Reinforced concrete pipe</td>
<td>AASHTO M170</td>
</tr>
<tr>
<td></td>
<td>c. Bituminous coated and paved aluminum corrugated pipe</td>
<td>AASHTO M196 &amp; M190</td>
</tr>
<tr>
<td>less than or equal to 4</td>
<td>a. Asbestos-Bonded, Bituminous coated and paved galvanized corrugated steel pipe</td>
<td>FH WW-P-405B Section 3.6.7 Coating G &amp; KyDOT Special Provision No. 7(76)</td>
</tr>
<tr>
<td></td>
<td>b. Reinforced Concrete Pipe with extra protection</td>
<td>AASHTO M170 &amp; KyDOT Special Provision No. 14 (76), Type V Cement (ASTM Spec. C150-72)</td>
</tr>
<tr>
<td></td>
<td>c. Vitrified Clay Extra Strength Pipe</td>
<td>AASHTO M65</td>
</tr>
<tr>
<td></td>
<td>d. Stainless Steel Corrugated Pipe</td>
<td>ASTM A409-72</td>
</tr>
<tr>
<td></td>
<td>e. Vitrified Clay Lined Reinforced Concrete Pipe</td>
<td>AASHTO M170 &amp; ASTM C479-72</td>
</tr>
<tr>
<td></td>
<td>f. Cast Iron Pipe</td>
<td>AASHTO M64</td>
</tr>
</tbody>
</table>
Inspection - An inspection procedure is extremely useful in maintaining the life of the pipes. Some reasons (given in a TRB study (22)):

"Culverts and pipelines of drainage systems require periodic inspection to detect corrosion-abrasion deterioration and other conditions affecting structural and hydraulic effectiveness.

"Another important reason for inspecting culverts is to evaluate performance of the various materials and corrosion-abrasion countermeasures in the specific natural environments encountered. Information on older culverts at or near a proposed site provides important points for any graphical or statistical correlation of the various environmental factors with service life. Evaluation of culvert materials that have been installed for shorter time spans yields less conclusive indications, because the short exposure time means that the protective layers and coatings are still relatively intact. Any failures or distress in newly installed culverts can, however, furnish highly significant information."

This publication provides information concerning the details of carrying out an inspection including scheduling, personnel, equipment and rating information. However, one point must be emphasized. For a program of this type to be effective, a data collection and retrieval system must be implemented.

Training - There is a great need to train department personnel because of the technical aspects of some of their work, such as the handling, bonding and placement of some of the culvert pipe and for activities such as inspection and maintenance. An example of the need for training was shown in the discussion where recommendations were made that linings of vitrified clay tile not be used because of the necessity for skill and craftsmanship in application.

Training must be an ongoing process because of changes in process and because of the problem of turnover of personnel. It is therefore recommended that Kentucky consider setting up training programs with relation to various aspects of handling and inspecting culvert pipe.
Additional Recommendations

Applications - It is recommended that specifications delineated in this report apply to new construction, betterments, and maintenance activities, whether the work is performed by contract or in-house forces. For each PH range there are sufficient viable options for types of pipe permitted by these recommendations so that the marketplace will determine which type will be used. This policy should also apply to construction partially funded by Federal-aid or to wholly funded state projects. There appears to be no justification for continuing separate policies. Permits for entrance pipes should require the installation of pipe that meets the requirements of these recommendations.

Force Account - When stockpiling pipe for force account work, initial pipe cost should not be the dominant factor, but the total cost including handling and installation costs for force account work, must also be considered in evaluating comparative pipe selections.

Pipe material specified for force account work should also conform to the recommendations presented. However, available personnel skills and maintenance and transportation equipment may limit the type of pipe that maintenance forces can handle. This qualification should be taken into account in the selection and stocking of types of culvert pipe for the state maintenance forces.

Review and Update - Specifications should be reviewed periodically and updated as new pipe materials and new type coatings are developed, proven and reach the market. However, a nationwide program should be implemented to control the testing of new materials.
Revision of State Manuals - All appropriate state design and reference manuals (soil, drainage, design, bridge, maintenance) should be modified to accommodate these specifications.
APPENDICES
APPENDIX A

QUESTIONNAIRE
1. Do you have specifications for pipe culverts in an acid water environment?
   Yes □ No □
   a. If yes, please send us a copy.
   b. If yes, are the specifications designed to cover both surrounding soil and water acidity?
      Soil and water: Yes □ No □
      Soil only: Yes □ No □
      Water only: Yes □ No □

2. Disregarding soil acidity, at what pH do you require special protection for culvert pipe:
   pH = ______

3. How are these special protection requirements applied:
   By potential acidic area in the state? Yes □ No □
   Stream by stream on the basis of testing? Yes □ No □
   Other: Please explain.

4. Do these special policies and specifications apply to:
   a. New Construction?
      - Contract Yes □ No □
      - In-house Yes □ No □
   b. Maintenance?
      - Contract Yes □ No □
      - In-house Yes □ No □
5. Do you have any quantitative or qualitative data on pipe deterioration in acid water environments? If so, may we have a copy of the information or could you reference the document or published paper. If you have a limited supply, would you loan a copy to us for a short period of time?

Signed: __________________________
Name

Title: ____________________________

State: ____________________________
APPENDIX B

COMPARATIVE POLICIES AND PRACTICES
ON SELECTION OF PIPE

Alabama B-1
Illinois B-2
Indiana B-2
Iowa B-3
Kansas B-3
New Jersey B-3
Ohio B-4
Pennsylvania B-9
Tennessee B-11
Virginia B-11
Washington B-12
West Virginia B-13
APPENDIX B

COMPARATIVE POLICIES AND PRACTICES
ON SELECTION OF PIPE

As a part of the study of Kentucky's policies and practices, BTML staff obtained information from a questionnaire (see Appendix A for a copy of the questionnaire) sent to states with conditions comparable with Kentucky: Illinois, Ohio, Pennsylvania, Tennessee, Virginia and West Virginia. This information as well as information obtained from other states through a literature search, the Kentucky 1977 Nationwide Survey (9), and personal contacts is included in this Appendix.

Alabama

A report on "Detrimental Effects of Natural Soil and Water Elements on Drainage Pipe Structures in Alabama" by Luther W. Hyde et al (10) provides some insights into their recommendations concerning water:

"If only water pH data are available for consideration in selecting pipe types, the following criteria should be adhered to for installations that are considered to equal the design life of the road:

- In areas where the pH of surface water is less than 4.5, drainage structures should be concrete or vitrified clay. In areas of highly mineralized acid mine drainage or where the pH is significantly less than 4.5, drainage structures should be vitrified clay or concrete with a proven protective coating.

- In areas where the pH of surface water is between 4.5 and 6.5, drainage structures should be concrete, bituminous-coated galvanized steel, or bituminous-coated aluminum.

- In areas where the pH of surface water is between 6.5 and 8.5, drainage structures should be concrete, galvanized steel, or aluminum.

- In areas where the pH of surface water is above 8.5, concrete, galvanized steel, or aluminum drainage structures may perform satisfactorily. However, at pH values significantly above 8.5, and in certain areas where alkaline pH is controlled by inorganic chlorides, nitrates, and sulfates, proven protective coatings may be required on all standard culvert materials.

B-1
- For pH values other than those above, special corrosion-resistant materials or protective methods should be applied.

**Illinois**

Illinois reported no specifications for pipe culverts in an acid water environment and no quantitative or qualitative data on pipe deterioration in acid water environments.

**Indiana**

Uncoated Steel and Aluminum pipes are not permitted under Interstate and State roads due to short life, easy damaging by grading equipment and unable to withstand fill heights.

Only bituminous coated corrugated steel used in peat areas to withstand corrosion and reduce weight.

Culverts in Acid and Mine water areas under the mainline pavement generally limited to vitrified clay or bituminous coated corrugated steel because of corrosion of concrete and uncoated metal pipes.

When the hydraulic analysis justifies the use of different sizes of pipes (concrete/steel) for the same structure, it will be necessary to specify metal pipes of one size and concrete pipes of another size as alternates for the same structure.

It is intended that all structures be designed to permit both concrete and metal pipe alternates.

Aluminum Alloy Pipe will not be permitted:
- When the pH content of the soil and/or the water carried by the structure is less than 4 or greater than 8 and;
- When the design hourly volume (DHV) is greater than 200 vehicles per hour (VPH).
Iowa

Primary roadway pipe is usually reinforced concrete. On other roads, the pipe is usually reinforced concrete or plain, corrugated steel as designated on the plans.

Designers frequently exclude corrugated steel, either plain or coated, where soil or moisture conditions usually result in short culvert life. Most of those locations are in the vicinity of coal mines.

Aluminum pipe is seldom specified.

Kansas

Specify reinforced concrete pipe when the culvert would be subjected to drainage from active coal mining areas.

Bids are taken on alternates of reinforced concrete pipe, corrugated iron or steel pipe, and reinforced concrete box. Vitrified clay and corrugated aluminum have been uneconomical and are not included in the alternate bid procedure.

New Jersey

Policy specifies the use of reinforced concrete pipe in all installations except where prohibited by design considerations.

Should design considerations such as hydraulics, load carrying capability, height of cover, construction limitations, etc. indicate that a type of pipe other than reinforced concrete would be more suitable at a particular installation, then the following service life expectancy criteria for metal pipe should be utilized in determining the type of pipe to be specified.
Survey the vicinity of the proposed installation and determine the corrosion performance history of any existing pipes. A pH value for the water at the proposed location should be determined. The average metal loss in mils per year is next determined.

The use of aluminum pipe in New Jersey is limited and aluminum should not be used where pH values are less than 4.5, greater than 8.5, or in areas subject to seawater.

**Ohio**

Ohio reported having specifications for pipe culverts in an acid water environment and requiring special protection for culvert pipe at a pH of 5.5 and below. The special protection requirements are determined through statewide stream by stream testing, especially in known acid areas and in potential acid areas where future conditions may warrant it (even though the present condition does not require the protection). Excerpts from the Ohio DOT Location and Design Manual (18) concerning specifications and processes for determining the pH factor and excerpts from a preliminary draft of "Durability Study of Pipes in Ohio" (16) which reviews the Ohio experience with different types of pipes as related to the pH factor follow:

**Ohio Department of Transportation**

**Location and Design Manual**

1104.25 UNUSUAL CONDITIONS. In areas where unusual acid or alkaline conditions in the dry weather flow are anticipated the following applies:

(a) pH value between 4.0 and 5.5 add the following protection:

1. Specify Type C for corrugated steel pipe 707.05 or 707.07. (Considering asbestos bonded here.)

2. Specify field paving for structural plate structures 707.03.
(b) Ph value below 4.0 or over 9.5 specify the following:

1. Vitrified clay pipe 706.08 E.S.

2. Reinforced concrete pipe 706.02 or 706.04 lined as per 706.05. (Vitrified clay liner plates bottom 1/3 or 1/2)

3. Reinforced concrete pipe 706.02, or 706.04 epoxy lined. When epoxy lined reinforced concrete pipe is specified or permitted as an alternate, the following note shall be added to the plans:

Conduit, _____*, Epoxy Coated, as per plan.

The bottom one-third of the interior barrel and joint surface areas of the concrete pipe, Sta. ___, 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 so as to obtain a continuous and relatively uniform and smooth lining with a minimum dry film thickness of 0.03 inches. All interior barrel surface shall be thoroughly inspected for holidays, utilizing an electrical instrument specially designed for that purpose. Just prior to installation of each joint of pipe in the field, a fibrated coal tar joint compound shall be applied around the inside corner of the bell or groove in accordance with the manufacturer's recommendations. Coating of the conduit shall be a plant operation and care shall be taken in the field to center the coated portion along the flowline.

The item description for epoxy coated concrete pipe should be in the following format, using the appropriate length, size and item number.

603 Lin.Ft. Conduit Type A 60" 706.02 Epoxy coated, as per plan.

*Add the pipe item number that applies, such as 706.02 or 706.04.

4. Asbestos bonded bituminous coated and paved corrugated steel pipe SS 942.

5. Structural plate corrugated steel pipe with SS 936 stainless steel bottom plates.

6. Structural plate corrugated steel pipe and pipe arches with a concrete paved bottom and an invert formed by 1/2 of a vitrified clay pipe.
(c) In highly acid soil conditions including culverts in trenches where backfill material could be saturated with acid or alkaline flow, specify the following:

1. Reinforced concrete pipe with exterior and interior protection as specified in 26b-3 above.

2. Asbestos bonded bituminous coated and paved CSP, SS 942.

3. Vitrified clay pipe 706.08 E.S.

(d) Where highly concentrated industrial wastes can be anticipated, conduits listed under 26-b-2 shall be used except that they shall be fully lined on the inside.

(e) The following policy shall govern the determination of the pH factor for the categories listed in the Pipe Policy.

1. The instrument used to measure the pH factor shall be capable of determining the pH within an accuracy of 0.1. Acceptable makes of instruments include:

   A Beckman Pocket pH Meter, model 18000; a Photovolt Portable pH Meter, model 126a; or an Analytical Pocket Size pH Meter, Model 34110-000. The suggestions are not intended to preclude the use of other comparable makes to those named.

2. The firm or agency responsible for the preparation of plans shall be responsible for obtaining the pH readings. A qualified employee of the Highway field district shall be present at all tests, whether or not the field district is responsible for the plan preparation.

3. A report shall be submitted, with the drainage review plans, listing the pH of the stream's flow at all conduit sites where corrosive flow is likely, the name of all personnel (including the field district personnel) present at the testing, the type of instrument used, and a statement that the tests were made of dry weather or low flow.

   Protection may be specified for a culvert with potential flow conditions more corrosive than measured, if the field district is of the opinion that future use of the contributing watershed will alter such conditions. A statement of this opinion, including the reasons for the opinion, shall accompany the pH report.

The following are excerpts from the preliminary draft of the "Durability Study of Pipes in Ohio." (16)
Analysis of bituminous protection of pipes - Bituminous coating on corrugated steel pipe and pipe arches lasted an average life of 3.16 years. For bituminous coated with bituminous paving (25% of circumference) corrugated steel pipe, the average life was 18.71 years. This was further broken down into approximately 12 years where overtopping of the paving occurred and approximately 25 years where no overtopping occurred.

There was no reference that the pH had an effect on the durability.

Corrugated Steel Culverts

"The effect of water pH on metal loss and ratings was significant throughout the range of pH encountered (2.5-9.0). However, the largest effect was noticed for values below 7.0 which is neutral. As pH decreased (acid content increased) the culvert conditions became worse with all other factors held constant. An example...is of a culvert only 10 years old and had the invert completely gone. Here water pH was 3.5."

"However, under either acid or abrasive conditions, the galvanizing which resists oxidation, has little effect as it is just as susceptible as the steel itself to those factors."

Concrete Pipe Culverts - Concrete ratings were based directly on concrete loss as opposed to indications such as rust and scale which were used to determine metal ratings. Behavior of concrete culverts differed based on ranges of water pH. The first groups with water pH equal and above 7.0 did not affect the condition of the culverts (7.0-9.5).

For water pH less than 7, the pH had a significant effect on concrete rating. Water pH had by far the most striking effect on concrete rating. As pH decreased from 7.0 ratings became worse at an increasingly severe rate and reached a critical state between 4.5 and 4.0. Water pH alone accounted for approximately 65% of the correlation between actual and predicted values of concrete ratings.
Vitrified Clay Liner Plates for Concrete Pipes - Most of those observed (14 ranging in age from 3 to 12 years and several others observed) reported in good condition with one exception where flow had overtopped the liner plates because of a large sediment buildup and some effect of mine acid on exposed concrete was noted.

Concrete Field Paving of Concrete Pipe -

"This has proven to be a stopgap measure with concrete paving deteriorating rapidly under acidic flow."

Coal Tar Pitch Coating for Concrete Pipe -

"The few culverts inspected with this protection indicated the same performance as that for bituminous coating of corrugated steel pipe. In no case had the protection lasted more than five years."

Coating and Field Paving of Structural Plate Pipe -

"In general bituminous coating of structural plate pipe, the coating, applied either in the field or at the factory, has performed as poorly as that for corrugated steel pipe...in low pH areas concrete paving with vitrified clay lined trough for very acidic dry weather flow has performed satisfactorily where observed."

Asbestos Bonded Bituminous Coating and Paving for Corrugated Steel Pipe -

"Twenty-nine asbestos bonded bituminous coated and paved corrugated steel pipe culverts (asbestos fibers embedded in molten zinc during galvanizing to which the coating adheres) were inspected in Ohio, Kentucky and Indiana. They ranged in age from two to twenty years (1972-1973 inspections) and most were exposed to extremely acidic flow with varying degrees of abrasiveness. Although paving in the older culverts was fairly heavily checked (cracked) in no case had the protection lost its adherence except at three joints in one culvert for areas of approximately one-half foot square. The bituminous coating and paving showed little sign of actual wear from flow. None of the culverts showed any evidence of metal deterioration under the protection."

Thermoplastic Coating for Corrugated Steel Pipe -

"As of December 1975, fifty-three thermoplastic coated (U.S. Steel Nexon) corrugated steel pipe culverts have been inspected one or more times....A Although no in-depth analysis of data was possible because of limited number of sites available and the short period of time the product had been in use in Ohio, several observations have been made upon which important conclusions regarding the durability of the thermoplastic coating."
"The thermoplastic coating is not affected by low pH flows. Of the 21 culverts exposed to flows with pH equal to 5.0 or under, none has shown any direct effect of the mine acid itself....However, acid flow does compound other problems which were observed at various sites."

- Problems unique to Helican Corrugated Lock Seam Pipe - forming of the lock seam appears to have had a detrimental effect on the bond between the thermoplastic and steel.

- Problems unique to Annular Corrugated Riveted Seam Pipe - rivets in the invert were rusted off in about 1.5 years. At very low pH the rivets in the invert should be protected or made of stainless steel. The exposed edge of the lamination is susceptible to peeling and in the case of low pH abrasive conditions will occur fairly rapidly.

- Detrimental effect of abrasive flow. Thermoplastic coating has shown a poor resistance to abrasive flow in addition to the aforementioned problems.

**Pennsylvania**

Pennsylvania has specifications for pipes in an acid water environment. Pennsylvania requires special protection for pipe at a pH of 5.0 (19). The various kinds of pipe required by Pennsylvania at various pH values follows.

**PENNSYLVANIA DEPARTMENT OF TRANSPORTATION**

**TABLE 2.12.15.2**

**SUGGESTED GUIDES FOR CORROSION PROTECTION BASED ON pH VALUES OF WATER**

Guide for the selection of pipe based on pH values of the water the installation is expected to carry.


**pH Values of Water or Soil**

**pH - 3.5 or less**
- Stainless Steel, Vitrified Clay, Clay Lined Reinforced Cement Concrete Pipe, Coal Tar Epoxy Lined Reinforced Cement Concrete Pipe, Coated Corrugated Galvanized Steel Pipe, Coated Aluminum Alloy Pipe.

**pH - 3.5 to 5.0**
- Coated Corrugated Galvanized Steel Pipe, PI.C.C. Pipe (24" Max.), Reinforced Cement Concrete Pipe or Coated Aluminum Alloy Pipe.

**pH - 5.0 to 8**
- Corrugated Galvanized Steel Pipe, PI.C.C. Pipe (24" Max.), Reinforced Cement Concrete Pipe, or Aluminum Alloy Pipe.

**pH - 8 and above**
- Coated Corrugated Galvanized Steel Pipe, Coated Aluminum Alloy Pipe, Reinforced Cement Concrete Pipe or PI.C.C. Pipe (24" Max.)

**High Sulfer Content**
- Same as 3.5 or less.

Note: In areas where highly abrasive conditions may exist, the metal pipe should have a Type A polymeric coating.

Requisitions for pipe should be supported with the pH of the affluent.

For design purposes, the pH of water at a future construction site shall be determined, in the field, by PTM 208. If the pH is found to be below 5.0 a one (1) quart sample shall be furnished to the Bureau of Materials, Testing and Research for exact identification. Such testing should be done seasonally, if possible, and the worst set of conditions used in making determination of proper type of pipe.

Further, at the discretion of the District Soils Engineer, if a site is considered to have exceptionally acidic or alkaline conditions, a six (6) to eight (8) pound sample of the site should be sent to the Bureau of Materials, Testing and Research for determination of soil pH and resistivity (ρ).

Selection of the type of polymeric coating required shall be made as per the following:

**Type A**

Water pH of less than 5.0 or greater than 8 combined with a soil pH of 5.0 to 8 and/or a soil resistivity of 6000 ohm/cm or greater.

**Type B**

Water pH of less than 5.0 or greater than 8 combined with a soil pH of 3.5 to 5.0 and/or a soil resistivity of 2000 to 6000 ohm/cm. A Type B polymeric coating shall be used for water with a pH of 3.5 to 5.0 if soil conditions are not being tested.
Type C

Water pH of less than 5.0 or greater than 8 combined with a soil pH less than 3.5 or greater than 8 and/or a soil resistivity of less than 2000 ohm/cm.

Tennessee

The 1977 nationwide survey of culvert practices by the Division of Research of Kentucky's Bureau of Highways (9) showed that:

"A specific type of culvert material may be specified for pertinent reasons such as unstable support, drains in embankment having inlet or outlet flowlines considerably higher than natural ground line, steep gradients, high acidity or alkalinity of soils and waters, or other corrosive elements or forces."

Virginia

Virginia replied to the questionnaire as follows:

"Investigation is made for underdrain installation only. Steel is not permitted if pH values fall outside of the range of 4-9. Aluminum is not permitted if the pH values are outside the limits of 5-8. We do not speak in the specifications regarding culverts. There may be cases where local field engineers may consider limitations during the field investigation stage. We have not experienced pipe failure that could be attributed to acidic conditions."

Further discussions with the Office of Materials Research for Virginia Department of Highways and Transportation, however, showed that an Instruc-
tional and Information Memorandum (LD-76(R)11.7) issued July 29, 1976 indicated the type of pipe culverts to be specified under varying conditions, i.e., pH of the water. Virginia's response to Kentucky's 1977 nationwide survey (9) was taken from this memorandum which states:

"Where the pH of the water is 4 or less, or 9 or greater; or where the installation will be subject to high abrasive action, concrete pipe only is to be specified regardless of the road system under which it is to be placed. The pH value indi-
cated on the Field Inspection Report Form is to be used for this."
They also said that field inspections are used to decide if the pH is outside the 4.0 to 9.0 range. If so only concrete pipe is permitted.

At this time, Virginia is also testing several coatings, including epoxy on corrugated metal pipe in highly acidic conditions.

**Washington**

Plain, corrugated steel pipe is excluded from use in Western Washington and steel and aluminum pipe require treatment for use in selected areas of Eastern Washington. These restrictions are a result of differences in soil pH between Western and Eastern Washington. The selected areas are defined by soil pH or bedload or stream or watercourse.

Aluminum pipe is not used in following cases:
1. Salt water environment
2. Clay backfill
3. Significant bedload in stream

Metal culvert pipe must be treated (Treatment 4 or 6) when pH of soil or water is less than 5 or greater than 9.

**Treatment 3:** Coated inside and out with asbestos fibers embedded in the spelter coating and then covered on both sides with asphalt.

**Treatment 4:** Coated as in Treatment 3 and with an asphalt paved invert.

**Treatment 6:** Coated as in Treatment 3 and with a 100% periphery inside spun asphalt lining.
West Virginia

West Virginia reported that they have guidelines in a design division directive for an acid water environment and require special protection for pipe at a value of 4.5 pH. These special protection requirements are applied on a stream by stream basis for testing (29). Additional information follows:

Excerpt from letter of March 9, 1979 from John C. Russell of the West Virginia agency to BTML:

"Regarding the enclosed Design Division Direction, DD-117, it should be noted that our policy concerning concrete culvert pipe in areas of coal mine drainage, referred to in the first paragraph, has been revised to utilize only concrete made with Type II (ASTM C150) cement."

Directive from West Virginia Department of Highways DD-117 (28):

TO: ALL PERSONS ENGAGED IN DESIGN

SUBJECT: DRAINAGE IN AREAS OF ACID ORALKALINE FLOWS

The Drainage Manual as revised June, 1966, required that in areas of coal mine drainage, concrete pipe or concrete box culverts would be used for mine drainage where required. Since that time additional field information and new materials have been made available on a general basis to the highway industry and consideration should be given to these types of facilities as well as concrete pipe.

Care should be taken in choosing type of pipe for use in culverts to ascertain the pH values of water to be carried by the pipe. Dry weather flows should be checked for concentration of acidity or alkalinity. If pH is less than 4.5 or more than 8.3 one of the following types of pipe should be provided:

1. Vitrified Clay Pipe
2. Partially Lined Invert Concrete Pipe

In cases where any unusual amount of heavy stone or other eroding substances can enter the pipe it will be desirable to designate Stainless Steel Pipe without alternates.

In cases of large structures such as box or arch culverts, which have a concrete bottom, it may be necessary to pave a dry weather flow channel of Vitrified Clay or other satisfactory material.
The remaining locations where the normal neutral flow is evident shall be provided with the alternates and the types of pipe that have been designated in the past.

All installations should be reviewed to provide the best type with respect to stability and permanence, structural adequacy and integrity as well as the adverse pH conditions.

Jack H. Samples, Director
Design Division
APPENDIX C

HRIS ABSTRACT

The 19 relevant abstracts from Highway Research Information Services (HRIS) supplied by Kentucky reviewed during preparation of the report are listed in five categories:

- Reports Used
- High pH Conditions
- Soil pH Only
- Polymer Concrete
- Plastic Pipe
Reports Used

Havens, J., "Durability of Culvert Pipe," Kentucky Department of Highways (August, 1968).(9)


Kinchen, R. et al, "Evaluation of Drainage Pipe by Field Experimentation and Supplemental Laboratory Experimentation (Interim Report 2)," Louisiana Department of Transportation (March, 1978)(13)


High pH Conditions


Soil pH Only


Welch, B., "Pipe Corrosion and Protective Coatings," Transportation Research Record 604, Transportation Research Board, (same as above).

Polymer Concrete

American Concrete Institute, "Development of Polymer-Impregnated Concrete as a Construction Material for Engineering Projects," American Concrete Institute Journal, (November, 1973).


**Plastic Pipe**


APPENDIX D

KENTUCKY DEPARTMENT OF TRANSPORTATION RESEARCH ACTIVITIES ON ALTERNATE CULVERT PIPE MATERIALS
APPENDIX D
KENTUCKY DEPARTMENT OF TRANSPORTATION RESEARCH
ACTIVITIES ON ALTERNATE CULVERT PIPE MATERIALS

The Kentucky Department of Transportation and its predecessor, the Kentucky Department of Highways, has been studying the problem of durability of various types of culvert material for thirty years. This effort was initiated when a culvert failed in the late 1940s. An investigation led to the conclusion that the failure was attributed to the acidity of the drainage water. As a result of this, the Research Division conducted a detailed survey of over 13,000 culverts in eastern and western Kentucky. A progress report was completed in December 1950.(1) Plain corrugated galvanized culverts suffered severe distress when located in areas with drainage water of high acidic content. The letter of submittal with that report recommended that a site-by-site survey be instigated to determine the acidity of the water prior to the pipe material selection. When an acidic environment exists, protective coatings should be applied.

To obtain more information on pipe durability, a culvert test program was initiated in which various types of pipe would be subjected to the same water environment. The site chosen was located at Morton's Gap in Hopkins County which had a continuous source of highly acid mine water (pH 3.0 to 3.5). The installation consisted of the following concrete and metallic pipes:

- Plain Reinforced Concrete Pipe
- Vitrified Clay Pipe (double strength)
- Asbestos-Bonded, Corrugated Metal (coated and paved)
- Corrugated Metal (plain galvanized)
• Corrugated Metal (double coated only)
• Corrugated Metal (paved and coated, Kentucky Specifications)
• Asbestos-Bonded, Corrugated Metal (seal-coated only)

All pipes were 24 inches in diameter.

The culvert survey continued through 1952 to complete the coverage of the Blue Grass area and the central portions of the state. The report, dated December, 1952, gave the first comprehensive analysis of the preliminary data from the Morton's Gap test installation.(3) Regarding the basic problem, the report stated:

• "Sulfur-bearing natural deposits such as shales and coals are the foremost, if not the only, sources of severely corrosive drainage waters of any consequence in the state.

• Drainage waters within the coal fields vary from mild to extreme acidity, but the vast majority of waters carried by highway culverts are only mildly acid or not acid at all.

• The acid potential is greatest in the Western Coal Fields because of its predominately high-sulfur coal and vast areas wasted by stripping.

• Severely acid drainage waters occur only within the coal fields, but mild acidity may occur at shale outcroppings within the Knobs or along deeply entrenched stream valleys in the Pennyroyal.

• Within potentially acid areas, concentrations of the acids are highest at the source but usually become diluted by other tributary water within a short distance downstream. Drainage structures contacting these waters near the sources are vulnerable to damage unless corrosion-resistant materials are used."

After identifying the source of the problem, conclusions were drawn on the comparative vulnerability of the pipe then in use or under test. These conclusions stated that:

• "Uncoated galvanized metal pipe has no resistance to acid water corrosion even under mild acidic conditions....

• Bituminous coated metal pipe is resistant to acid corrosion as long as the coating insulates the metal from contact with acids." (However, at the time of this report it was stated that limited examples from field surveys and limited exposure time of the test
installation did not give a basis for estimating life expectancy. Information available from other sources, however, indicated a life expectancy for this type of pipe to be at least 15 years in acid water.)

- "Concrete pipe is resistant to corrosion except under considerations of extreme acidity. In highly acid waters the anticipated service life should be in the range of 5 to 15 years. Under conditions other than these concrete pipe is suitable in any installation designed for permanent use."

It was also observed that concrete pipe made with siliceous gravel aggregate was more resistant to severely acidic conditions than pipe made with limestone aggregate.

- "Vitrified clay pipe is the only culvert material now in use that is totally inert to corrosion by even the most severe drainage waters."

At the same time that the culvert survey was underway, an impromptu investigation was made of the corrosive damage to concrete bridge piers, box culverts and metal arches in Hopkins County. The results of this damage are in a report by the Research Division dated June, 1952.(2)

After the bituminous coated corrugated steel pipe had been in service 4 or 5 years, the Research Division conducted a survey reported by E. M. West of the Research Division in November, 1954 (26) which disclosed:

- "A frequency of damage due to fire;
- Cracking and peeling where exposed to sunlight;
- Improper positioning of paved inverts during installation."

Also presented were a number of observations from the Morton's Gap test installation, which also served as a status report on that project. While the survey was in progress, large structural plate arches were discovered which showed serious corrosion and even failure. A survey of these structures was made and reported by E. M. West in March, 1957.(27)
The Department of Highways continued its efforts by reporting on the results of the Morton's Gap test area. (4) This report by J. H. Havens, dated February, 1960, gives a history of the test installation and a chronology of the various activities from the date of installation, April, 1951, through February, 1960. It further summarized the condition of each pipe that had been installed in the test site.

During June and July, 1964, pipes, culverts and bridges on several state highways and at Morton's Gap were inspected. Features such as land-use (strip mine, woodlands or farm land) and culvert conditions (etching, bond qualities of coatings and sittings) were noted. Photographs were taken, pH measurements were made and comments were given about each location and detailed inspection notes were taken. This memorandum by John W. Scott to the Director of Research summarized these data. (21)

Following this, a report entitled "Considerations Regarding Type of Culverts; Pennyrile Parkway" dated June, 1966, by J. H. Havens (5) related the effects expected from acid waters on culverts under the Western Kentucky Parkway, the Madisonville by-pass and the Morton's Gap test site.

In 1968 the Division of Research issued a report "Durability of Culvert Pipe," (6) which was a review of the previous 20-year effort by the Department in developing durability data on various types of culvert material. The report stated that

"it has been demonstrated that both reinforced concrete pipe and bituminous coated corrugated pipe do not provide life expectancies of 20 years in environments when the pH is in the range between 3.5 and 2.8. Moreover, 20 years is not commensurate with the expected terms of service of a road...which may be 100 years, more or less."

The report also pointed out that in the past, blanket exclusions, i.e., by designating certain counties as acid, had been used as a control where
the risk of potential or latent acidity precluded site-by-site methods of control. However, the report then stated, "the only method of control that is not otherwise punitive in its application is a site-by-site method."

A review of the evidence on hand on the durability of pipe culvert materials was addressed in a memorandum prepared by R. D. Hughes of the Research Division (8) leading to a proposed criteria for specifying alternate types of culvert pipe for various environments. He also proposed criteria for box culverts and bridge piers.

In view of the continuing increase in knowledge on pipe durability, the Kentucky Department of Transportation issued two special provisions, dated June 23, 1976.

Special Provision No. 7 (76): Asbestos-Bonded Bituminous Coated and Paved Corrugated Metal Pipe.

Special Provision No. 14 (76) Reinforced Concrete Pipe with Extra Protection.

The Department has continually revised its manuals to be sure that these documents reflect changes in knowledge on this subject. For example, the Bridge Division Manual, Section 66-05.0516, Acid Water Design,

"To increase the resistance to acid content in water provide an additional two inches of cover on the bottom slab and the toe of the wing footings. The thickness of the sidewalls, interior walls, and wingwalls shall also be increased two inches for a height of 12 inches above the flow line. For this design, the construction joint between the wall and the bottom slab is to be placed 12 inches above the flow line."

The latest report was a "Summary of Nationwide Survey of Culvert Practices" by R. D. Hughes, Division of Research, September, 1977 (9), which tabulated responses to a questionnaire regarding the permissible use of various types of pipe culvert materials.
REFERENCES


REFERENCES (Continued)


17. ODOT, Response to BTML Questionnaire (1979).


20. PennDOT, "Suggested Guides for Corrosion Protection Based on pH Values of Water," (Rev. 2-77-2.12.15.04), Table 2.12.15.2.


