Bibliography
Pipe Material Durability

Introduction

A least cost analysis is an effective method of evaluating two alternate materials with different service lives for economic equivalence. The factors which affect the analysis are project design life, material life, first cost, interest rate, inflation rate, replacement costs, and residual value.

First cost of a pipe material is important to the engineer and owner, but does not reveal the entire cost of the pipeline. If the service life of an alternate material is less than the project design life, future replacement costs must be considered. Least cost analyses over the project design life indicate which material will be the most economical. The material service life is a key factor in any least cost analysis and determining an expected service life for different materials in different localities can be an exceedingly difficult task. As an aid to designers, this Buried Fact discusses the results of a literature search and presents a bibliography on pipe material durability.

Material Service Life

Major specifying agencies, such as the Federal Highway Administration, Corps of Engineers, Soil Conservation Service, and most state departments of transportation have published reports on field and laboratory investigations to determine the durability of pipe materials and establish methods for predicting service life.

A literature search in 1983 indicated 28 states and numerous researchers had performed culvert surveys and investigated the durability of pipeline materials since 1925, resulting in 131 reports. For this publication, the literature search was updated in 1991 to a total of 153 reports.

Since the durability of concrete pipe has been so evident, and research money is normally spent only on problems, 59 percent of the reports are concerned primarily with the deterioration and short service life of corrugated metal pipe; 26 percent of the reports cover multiple pipe materials; 6 percent of the reports deal with only concrete; and 9 percent are on other materials or general subjects. The complete bibliography is presented at the end of this publication.

Comprehensive Reports

It was the mid-60's before some states began developing comprehensive surveys, and gathered data on all pipe materials, not just those exhibiting problems. The nine most comprehensive reports and major conclusions are briefly discussed in the following paragraphs.

"Concrete culverts were not inspected on an organized basis as were the metal culverts. ...Concrete culverts, when constructed on a firm foundation, not overloaded and not subjected to abrasive wear, should last almost indefinitely. Numerous culverts were examined which appeared as new, even though they were installed over 25 years ago. No appreciable signs of material disintegration or chemical attack were found."

1969 - Detrimental Effects of Natural Soil and Water Elements on Drainage Pipe in Alabama, L.W. Hyde, et. al., Alabama Highway Department.

"Concrete is resistant to corrosion except under conditions of extreme acidity or alkalinity. ...However, under conditions other than extreme acidity or alkalinity, concrete pipe can be expected to give many years of satisfactory service. ...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."

1973 - Corrugated Steel Pipe for Storm Drains, A Value Engineering Study, Los Angeles County Flood Control District.

"Presently, storm drains are constructed using primarily reinforced concrete pipe or box. ...For the past 8 or 9 years, the Corps has used only reinforced concrete pipe in this area. ...However, almost all of the jurisdictions within the County are replacing corrugated steel pipe with reinforced concrete pipe when the need arises. The main reasons given are high main-

tenance costs attributed to the need for frequent, thorough inspection, and limited maintenance personnel."

1977 - Performance of Culvert Materials in Various Colorado Environments, H.N. Swanson, et. al., Colorado Division of Highways.

"Concrete sections made of Type II cement, Type II low alkali, Type II low C3A and Type V cements were placed at the Fruit and the Olathe sites in 1974 and 1975. Samples made with Type II and Type V cement were placed in Fossil Creek in 1986. All of the above concrete samples are sound and in good condition. Sections of concrete pipe, one made with regular aggregate and one with limestone aggregate have been exposed to the acidic conditions of the Straight Creek site for five years. ...The areas exposed to water show definite attack by the acid water. Attack has only removed the cement surface, exposing the aggregate. The attack is not very serious and the pipe under the highway is expected to remain in service for at least another twenty years."

1979 - Kentucky Culvert Study, Byrd, Tallamy, MacDonald and Lewis.

"Acid environment (greater than 4 pH and less than or equal to 6 pH) ...The reinforced concrete pipe is still appropriate in this pH range. "Extremely Acid Environment (pH equal to or less than 4) ...Concrete pipe requires special protection to provide an acceptable risk level for adequate service life."
"Concrete is usually used in severely corrosive areas. Most concrete is installed uncoated."

1980 - Evaluation of Metal Drainage Pipe Durability - Analysis After Six Years, R.W. Kinchen, Louisiana Department of Transportation.
"The Department's hydraulics engineers can generally choose either reinforced concrete or corrugated metal pipe in their designs. Concrete pipe is very durable and with stable bedding conditions can normally serve effectively for the life of a highway. The LADOT also recognizes that metal pipe has its place in the field of hydraulics and maintains an interest in innovations in metal pipe. The major drawback with metal pipe is its tendency to corrode in the presence of moisture, oxygen, and salt."

1987 - Study of Use, Durability and Cost of Corrugated Steel Pipe, Missouri Highway and Transportation Department.
"In Missouri, roadbeds and highway corridors are selected and designed with no foreseeable intent to relocate. At the present time, approximately 25 percent of the Department's roadbeds are already 50 years or older and 74 percent are over 25 years of age. Current field reports show that CSP is being replaced as early as 20 years of age due to rusting out of the lower portion of the flowline (invert)."
"It is recognized that CSP has a lower initial installed cost than RCP. However, CSP is expected to be replaced one to four times during the anticipated life of an RCP."
"At this time, it is concluded that in order for CSP to be an equal alternate to RCP for culverts under roadways carrying high volumes of traffic, the pipe should have an expected life of at least 100 years."
"Current coatings for corrugated steel pipe are all susceptible to degradation under certain conditions, particularly abrasion."

1991 - Life Expectancy Determination of Zinc-Coated Corrugated Steel and Reinforced Concrete Pipe Used in Missouri, MR91-1, Missouri Highway and Transportation Department.
"This study indicates that CSP will generally be deteriorated to the point of needing replacement at approximately 44 years with a range from 15 to more than 60 years. The mode of failure for CSP is nearly always due to rusting out of the invert or bottom portion of the pipe. Due to insufficient number of RCP having deteriorated to the point of needing replacement, it was not possible to arrive at a realistic age for RCP replacement. The greatest problem noted with RCP is disjoining at the end pipe sections. With the durability rating system established for this survey, those pipe in need of replacement are 45.6% of the CSP and 0.3% of the RCP surveyed. Since 1987, district pipe replacement records indicate that 964 crossroad CSP have been replaced having an average age of 41.4 years."
"Records from Maintenance and Traffic Division indicated that approximately 178,656 feet of CSP (including crossroad and entrances) has been replaced in the last 5 years (1985 thru 1989)."
"What are the costs of replacing pipe? Maintenance and Traffic records (See Appendix E) show that in the last 5 years (1985 thru 1989) MHTD has spent over 5 million dollars in the replacement of CSP. Cost of RCP replacement for the same 5 year period was $239,000. The mean (average) cost of material and installation over this 5 year period per lineal foot of pipe was $27.54 and $41.08 for CSP and RCP respectively. Significantly higher costs should be realized for replacement of pipe in the future if trends identified by this survey are true."

Service Life Prediction

Review of the following bibliography indicates substantial and comprehensive research was actually done to investigate concrete pipe both prior to and after the start of the Ohio DOT study in 1972 (See References 69-71). The data from these investigations, however, shows that the performance of concrete pipe was so good that the development of predictive service life equations was meaningless, and, instead, general statements were made to the effect that concrete pipe would last indefinitely in normal environments. Initially, even the Ohio study was afflicted with this problem.

For the Ohio study, both the concrete and corrugated steel pipes were randomly selected for investigation. To obtain a meaningful service life equation for concrete pipe, however, only the data from sites with a pH of less than 7 were statistically analyzed. A look at the overall study indicated the excellent performance of concrete pipe for out of 519 concrete culverts studied, only 9 were rated in poor condition, 33 in fair condition and 477 in excellent condition. Of the nine in poor condition, one has been repaired, and repairs are contemplated for the other eight.

Another difficulty in pipe investigations is the establishment of objective and equal rating classification systems. For example, in the Ohio study, concrete pipe was rated poor when there was significant loss of mortar and aggregate from the surface or when the concrete surface was in a softened condition, while the corrugated steel pipe was rated poor when the invert was lost, there was perforation or when the pipe could be penetrated by a geologist's
hammer - clearly not comparable ratings, indicating that the predictive equations for corrugated steel pipe are liberal. If, as for corrugated steel pipe, concrete pipe was rated poor only when its invert was lost, then the service life of concrete pipe would be unlimited in even adverse environments.

The following bibliography is presented in two sections. The first section lists surveys and reports on culverts chronologically by individual states. The second chronological list presents miscellaneous pipeline surveys and reports.

**BIBLIOGRAPHY**

**State Culvert Surveys And Reports**

**ALABAMA**

1. Iso-pH Maps Identify Areas Detrimental to Drainage Structure Performance Life, Oliver, J.C., and Palmere, R.D., Highway Research Record 56, 1964.


**ARIZONA**


**CALIFORNIA**


**COLORADO**


**GEORGIA**


**IDAHO**


**INDIANA**


**IOWA**


**KANSAS**


KENTUCKY

LOUISIANA

MAINE

MARYLAND

MICHIGAN

MINNESOTA

MISSISSIPPI

MISSOURI
54. Life Expectancy Determination of Zinc-Coated Corrugated Steel and Reinforced Concrete Pipe Used in Missouri, Missouri Highway and Transportation Department, MTR1-1, 1991.
MONTANA

NEBRASKA
58. Nebraska Soil Resistivity and pH Investigation as Related to Metal Culvert Life, Nebraska Dept. of Roads, April, 1969.

NEW JERSEY

NEW YORK
64. Polymer Coating for Corrugated Steel Pipe, Special Report 64, N.Y. DOT, 1979.
66. New York State Precast Concrete Box Evaluation, N.Y. DOT Memorandum, October 23, 1981.

OHIO

OKLAHOMA

OREGON

PENNSYLVANIA


VIRGINIA


WASHINGTON


WEST VIRGINIA

90. Corrugated Metal Culvert Pipe Test Using Highly Acid Mine Waters, State Road Commission of West Virginia, Division of Tests, 1928-29, unpublished.


BIBLIOGRAPHY

Miscellaneous Pipeline Surveys and Reports


15. Microbiological Studies Reveal Significant Factors in Oil and Gas Pipeline Back-Filled Ditches, Dr. J.O. Harris, Kansas State University, Dec., 1963.


33. Corrugated Steel Pipe Study - Corps of Engineers (Omaha Report), Corps of Engineers, 1975.
43. Focus on External Corrosion, American Concrete Pipe Association, 1981.
45. Purdue University Evaluation of Out-of-Roundness Tolerances, Purdue University, 1982.