BURIED facts

American Concrete Pipe Association

Bibliography Pipe Material Durability

Selecting pipe materials best suited for service as a storm sewer, culvert, sanitary sewer, or small bridge replacement is of primary importance to the design engineer. Selection is based on hydraulic efficiency, structural integrity, durability and cost. Most engineers are well acquainted with hydraulic and structural design criteria, but the effect of product durability on the total cost may not be clearly understood. On many projects when alternate materials are bid, selection is too often based on first cost. However, the alternate with the lowest first cost may not be the most economical selection for the design life of the project. The most economical alternate must be determined through a least cost analysis.

C.P. Information No. 11 reviews the significance of various physical and chemical factors which may be aggressive to concrete pipe; the significance of pertinent service factors and concrete pipe properties; and durability design and the performance of concrete pipe.

american concrete pipe association

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.

1965 - A Culvert Material Performance Evaluation in the State of Washington, *V.E. Berg, Washington State Highway Commission.*

"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 maintenance 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 Fruita and the Olathe sites in 1974 and 1975. Samples made with Type II and Type V cement were placed in Fossil Creek in 1966. 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."

1980 - Evaluation of Highway Culvert Coating Performance, *Federal Highway Administration, Report No. FHWA/RD-80-059.*

"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 disjointing 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 Palmore, R.D., Highway Research Record 56, 1964.*
2. **Detrimental Effects of Natural Soil and Water Elements on Drainage Pipe Structures in Alabama,** *Hyde, L.W., Shamburger, V.M., Ellard, J.S., and Pate, R.E., Report No. HPR 40, Geological Survey of Alabama Water Resources Division, 1969.*

ARIZONA

3. **Corrosion of Highway Metal Structures and Cathodic Protection,** *Dana, J.S., Final Rep., Arizona Hwy. Dept. Nov., 1973.*
4. **Corrosion of Highway Structures,** *James S. Dana and Rowan J. Peters, Arizona Department of Transportation, January, 1975.*
5. **Tucson Verifies Pipe's Durability,** *Public Works Magazine, December, 1982.*

CALIFORNIA

6. **Final 20-Year Report on the Corrugated Metal Culvert Field Test Started in 1929-30,** *Stanton, T.E., California Division of Highways, July, 1950, unpublished.*
7. **Report on the Experimental Placing of a Cement Mortar Coating in Corrugated Metal Culverts in District,** *Stratfull, R.F., California Div. of Hwys. memo, May, 1954, unpublished.*
8. **Corrosion of Corrugated Metal Culverts in California,** *J.L. Beaton and R.F. Stratfull, Highway Research Board, Highway Research Bulletin 223, 1959.*
9. **A Progress Report on the Study of Culvert Deterioration,** *Stratfull, R.F., California Division of Highways, 1960.*
10. **A New Test for Estimating Soil Corrosivity Based on Investigation of Metal Highway Culverts,** *Stratfull, R.F., Corrosion, Vol. 17, No. 10, Oct., 1961.*
11. **Field Test for Estimating Service Life of Corrugated Metal Pipe Culverts,** *Beaton, J.L. and Stratfull, R.F., Highway Research Board, Proceedings Vol. 41, 1962.*
12. **Highway Corrosion Problems, Metal Culverts and Reinforced Concrete Bridges,** *Stratfull, R.F., Western Region Conf. Nat'l. Assn. of Corrosion Eng., Oct., 1962.*
13. **Field Method of Detecting Corrosion Soil Conditions,** *Stratfull, R.F., Proc. 15th Calif. St. and Highway Conference, I.T.T.E., Univ. of California, 1963.*
14. **Highway Corrosion Problems, Materials Protection,** *Vol. 2, No. 9, September, 1963.*
15. **Method for Estimating the Service Life of Metal Culverts,** *Test Method No. Calif. 643-B, California Division of Highways, Materials and Research Dept., Sacramento, California, July, 1963.*
16. **A Preliminary Study of Aluminum as a Culvert Material,** *by E.F. Nordlin and R.F. Stratfull, Highway Research Board, Highway Research Record No. 95, 1965.*
17. **California's Culvert Research Program-Description, Current Status and Observed Peripheral Pressures,** *R.E. Davis and A.E. Bacher, Highway Research Board, Highway Research Record 249, 1968.*
18. **Corrugated Steel Pipe for Storm Drains,** *Los Angeles County Flood Control District, 1973.*
19. **Cooperative Field Survey of Aluminum Culverts - 1979,** *John A. Apostolos and Forrest A. Myhres, California Department of Transportation, 1980.*

COLORADO

20. **Culvert Performance at Test Sites in Colorado** *(1962-1968), Res. Rep. No. 68-8. Colorado Div. of Hwys., Aug., 1968.*
21. **Performance of Culvert Materials in Various Colorado Environments,** *Colorado Division of Highways, Report No. CDOH-P&R-R-77-7, September, 1977.*

GEORGIA

22. **Report on Study of Culvert Durability,** *Slack, S.B. and Abercrombie, W.F., State Highway Board, Georgia State Highway Department, 1928, unpublished.*
23. **Studies in Pipe Culvert Durability and Performance,** *Slack, S.B., Engineering News Record, Vol. 104, No. 23, June 5, 1930.*

IDAHO

24. **A Study of Durability of Culvert Pipe, Materials Section,** *State of Idaho, Department of Highways, 1957, unpublished.*
25. **A Study of the Durability of Metal Pipe Culverts,** *Idaho Department of Highways, Surveys and Plans Division, April, 1965.*
26. **Durability Design Method for Galvanized Steel Pipe in Iowa,** *Malcolm, W.J., Corrugated Metal Pipe Assn. of Iowa & Nebraska, Spring, 1968.*
27. **Idaho-Aluminum Pipe Report,** *State of Idaho Transportation Department, 1977.*

INDIANA

28. **Installation Problem With 66-Inch Corrugated Metal "Smooth Flo" Sewer Pipe,** *American Concrete Pipe Association, 1957.*
29. **Pipe Coating Study,** *Sudol, Indiana Dept. of Hwys. Sept., 1982.*

IOWA

30. **Durability Design Method for Galvanized Steel Pipe in Iowa,** *Malcolm, W.J., Corrugated Metal Pipe Association of Iowa and Nebraska, 1968.*

KANSAS

31. **Report of Pipe Culvert Corrosion in Selected Areas of Southeast Kansas,** *Graf, N., James D., and Wendling, W.H., Bureau of Public Roads in Cooperation with the State Highway Commission of Kansas, 1965.*

32. **Corrosion of Corrugated Metal Pipes: Progress Reports,** *Worley, Herbert E., Submitted to Bureau of Public Roads, in 1968 and 1969.*

33. **Effectiveness of Bituminous Coatings on CMP,** *State Highway Commission of Kansas, 1970.*

34. **Corrosion and Service Life of Corrugated Metal Pipe in Kansas,** *Worley, H.E., and Crumpton, C.F., Hwy. Res. Record No. 412, 1972.*

KENTUCKY

35. **A Survey of Acidity in Drainage Waters and the Condition of Highway Drainage Installations: Progress Report No. 2,** *Havens, J.H., Kentucky Dept. of Highways, December, 1952.*

36. **Considerations Regarding Type of Culverts; Pennyrile (Pennyroyal) Parkway,** *Havens, J.H., Kentucky Dept. of Hwys., Aug., 1966.*

37. **Durability of Culvert Pipe,** *Havens, J.H., Kentucky Dept. of Hwys., Aug., 1968.*

LOUISIANA

38. **Drainage Pipe Study,** *Azar, D.G., Research Rep. No. 57, Louisiana Dept. of Hwys., May, 1971.*

39. **Corrugated Metal Pipe Research,** *Louisiana D.O.T., 1978.*

40. **Evaluation of Metal Drainage Pipe Durability Analysis After Six Years,** *Louisiana D.O.T. and Development, 1980.*

41. **Evaluation of Drainage Pipe by Field Experimentation and Supplemental Laboratory Experimentation. Interim Report #3,** *Louisiana D.O.T., 1981.*

MAINE

42. **Zinc Content of Streams With Corrugated Metal Pipes,** *Jacobs, K.M., Tech. Paper 74-2, Maine D.O.T., Jan., 1974.*

43. **Durability of Drainage Structures,** *Jacobs, K.M., Maine D.O.T., June, 1982.*

MARYLAND

44. **Statewide Survey of Bituminous Coated Only, and Bituminous Coated and Paved Corrugated Metal Pipe,** *Maryland State Roads Commission, 1971.*

MICHIGAN

45. **Corrosion of Galvanized Metal Culverts in Michigan, Interim Report,** *R.W. Noyce and R.W. Ostrowski, Michigan Dept. of State Highways and Transportation, January, 1974.*

46. **Corrosion Performance of Aluminum Culverts,** *Ellis, J.T., Second Progress Rep., Res. Rep. R-679, Michigan Dept. of State Hwys., Dec., 1968, Final Progress Rep., Res. Rep. R-976, Nov., 1975.*

47. **Statewide Corrosion Survey and Recommendation for a Site Evaluation Program for Proposed Culvert Locations,** *Michigan Dept. of State Hwys. and Transportation, 1976.*

48. **Michigan Galvanized Metal Culvert Corrosion Study,** *Michigan Dept. of State Hwys. and Transportation, 1979.*

MINNESOTA

49. **Durability Design Method for Galvanized Steel Pipe in Minnesota,** *Holt, A.R., Minnesota Members of National Corrugated Steel Pipe Assn., 1967.*

50. **Serviceability of Corrugated Metal Culverts,** *Kill, D.L., Investigation No. 116 Final Rep., Minnesota Dept. of Hwys., 1969.*

MISSISSIPPI

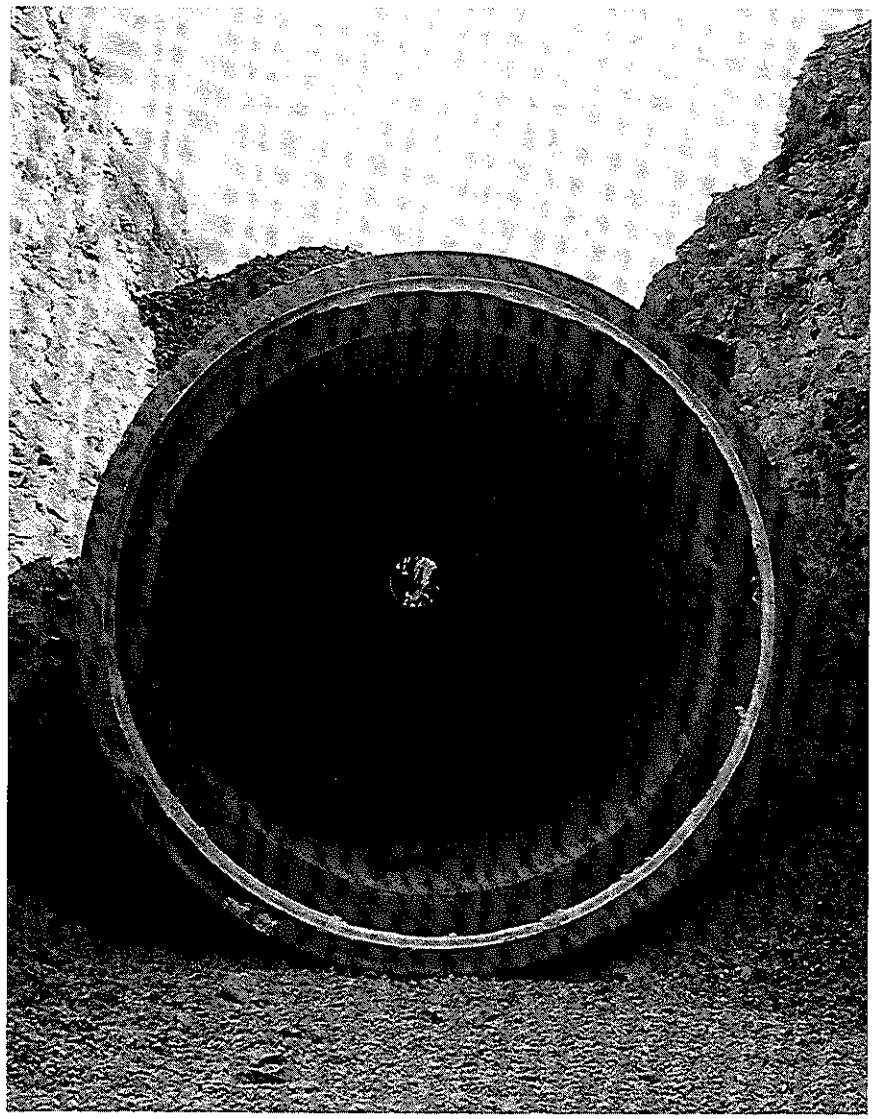
51. **Mississippi Pipe Evaluation Study,** *Brown, R., Paper Presented Before Southeastern Association of State Highway Officials, 1964.*

52. **1964 Pipe Evaluation Study Supplement,** *Eubank, D., and Thomas, H.D., Mississippi State Hwy. Dept., 1964.*

MISSOURI

53. **Study of Use, Durability and Cost of Corrugated Steel pipe,** *Missouri Highway and Transportation Department, 1987.*

54. **Life Expectancy Determination of Zinc-Coated Corrugated Steel and Reinforced Concrete Pipe Used in Missouri,** *Missouri Highway and Transportation Department, MR91-1, 1991.*



MONTANA

55. **Research on Bolt Failures in Wolf Creek, (Mont.) Structural Plate Pipe,** *John W. Macsdain, Armco Steel Corp., Highway Research Board, Highway Research Record, No. 144, 1966.*

56. **Rebuilt Wolf Creek Culvert Behavior,** *A.C. Scheer and G.A. Willett, Jr., Highway Research Board, Highway Research Record No. 262, 1969.*

NEBRASKA

57. **Durability Design Method for Galvanized Steel Pipe in Nebraska,** *Bearg, E.A., et. al., Armco Steel Corp., 1966-67.*

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

NEW JERSEY

59. **Corrosion of Corrugated Metal Pipe,** *Ray, D., and Croteau, J., Final Rep., New Jersey DOT, Feb., 1974, unpublished.*

NEW YORK

60. **Pipe Corrosion and Coatings,** *Larson, E., New York, 1938.*

61. **Drainage Basin Survey Series Reports,** *N.Y. State Dept. of Health, 1952-63.*

62. **Durability of Corrugated Metal Culverts,** *Haviland, J.E., Bellair, P.J., and Morrell, V.D., Research Report 66-5, State of New York, Dept. of Transportation, Nov., 1967.*

63. **Durability of Corrugated Metal Culverts,** *State of New York, Dept. of Transportation, Hwy. Research Board, Hwy. Research Record No. 242, 1968.*

64. **Polymer Coating for Corrugated Steel Pipe, Special Report 64,** *N.Y. DOT, 1979.*

65. **National Survey of State Culvert Use and Policies,** *Wallace W. Renfrew and Robert M. Pyskadlo, Special Report 68, N.Y. State DOT, May, 1980.*

66. **New York State Precast Concrete Box Evaluation,** *N.Y. DOT Memorandum, October 23, 1981.*

67. **Durability of Asphalt Coating and Paving on Corrugated Steel Culverts in New York,** *W.W. Renfrew, New York State DOT Special Report 80, 1984.*

68. **Metal Loss Rates of Uncoated Steel and Aluminum Culverts in New York,** *Peter J. Bellair and James P. Ewing, New York State DOT Special Report 115, 1984.*

OHIO

69. **Culvert Durability Study (Interim Report),** *Ohio DOT, 1972.*

70. **Ohio Culvert Durability Study,** *Ohio DOT, 1982.*

71. **Durability of Bituminous-Lined Corrugated Steel Pipe Storm Sewers,** *Ohio Department of Transportation Research and Development, 1985.*

72. **Evaluation of Corrugated Metal Pipe Arches, Final Report,** *Volume I, Ohio DOT, 1988.*

OKLAHOMA

73. **Service Life of Metal Pipe Culverts As Affected By Corrosion,** *Oklahoma Dept. of Hwys., Research & Development Div., Memo No. 2, 1965.*

74. **A Study of the Durability of Corrugated Steel Culverts in Oklahoma,** *C.J. Hayes, Oklahoma Dept. of Hwys., 1971.*

OREGON

75. **Culvert Inspection, Oregon and Washington,** *Armco Drainage and Metal Products Co., Inc., Portland, Oregon, 1932, unpublished report, author unknown.*

76. **Culvert Inlet Failures - A Case History,** *Roy C. Edgerton, Oregon State Highway Dept., 1961.*

77. **Condition Survey Report, Asbestos-Bonded Steel Culverts in Western Oregon,** *Sol Deocampo, Terry Gruber and Bruce Wasill, Federal Highway Administration, 1976.*

PENNSYLVANIA

78. **Culvert Pipe Survey,** *State of Pennsylvania, Dept. of Hwys., 1930 (approximate).*

UTAH

79. **Evaluation of Aluminum Alloy Pipe for Use in Utah's Highways,** *Peterson, D.E., Utah State Hwy. Dept., June, 1973.*
80. **Pipe Corrosion and Protective Coatings,** *Utah State Dept. of Highways, 1974.*
81. **Pipe Culvert Durability,** *Utah Department of Transportation, Interim Report, 1988.*

VIRGINIA

82. **An Investigation of Bituminous Coated Corrugated Metal Pipe,** *Sheppe, R.L., Virginia Dept. of Highways, Div. of Tests, Research Section, Nov., 1946, unpublished progress report.*
83. **Comparative Study of Aluminum and Steel Culverts: Progress Report No. 1,** *Mitchell, R.A., Virginia Council of Highway Investigation and Research, Oct., 1962.*
84. **Comparative Study of Aluminum and Steel Culverts: Progress Report No. 2,** *Turner, T.F., Virginia Council of Highway Investigation and Research, Nov., 1963.*
85. **Comparative Study of Aluminum and Steel Culverts: Progress Report No. 3,** *McKeel, W.T., Jr., and Turner, T.F., Virginia Council of Highway Investigations and Research, Feb., 1965.*
86. **A Comparative Study of Aluminum and Steel Culverts,** *McKeel, W.T., Jr., Culvert Studies Progress Rep. No. 4, Virginia Highway Res. Council, May, 1971.*

WASHINGTON

87. **Culvert Inspection, Oregon and Washington,** *Armco Drainage and Metal Products Co., Inc., Portland, Oregon, 1932, unpublished report, author unknown.*
88. **Statewide Culvert Survey,** *Smith, Frederick, C., State of Washington, Dept. of Hwys., 1937, unpublished report.*
89. **A Culvert Material Performance Evaluation in the State of Washington,** *N.E. Berg, Dept. of Hwys., Washington State Hwy. Commission, Research Project No. HPR-1-2, 1965.*

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.*
91. **A Survey of Culverts in West Virginia,** *Downs, W.S., Research Bulletin No. 13, West Virginia University Engineering Experiment Station, Dec. 15, 1934.*

BIBLIOGRAPHY

Miscellaneous Pipeline Surveys And Reports

1. **Progress Report on Culvert Investigation,** *Crum, R.W. and Morris, Mark, Proc. Fifth Annual Meeting of the HRB, Washington, D.C., Dec., 1926.*
2. **Report on Culvert Investigation,** *Crum, R.W., Proc. Seventh Annual Meeting of the HRB, Washington, D.C., Dec., 1927*
3. **Report on Culvert Investigation,** *Crum, R.W., Proceedings, Highway Research Board, Vol. II, Part II, 1931.*
4. **A Study of Bituminous-Coated Corrugated Sheet Metal Culverts,** *Welborn, J.Y., and Serefin, P.J., Public Roads, Vol. 24, No. 9, July-August, Sept., 1946.*
5. **Look Into Your Culverts,** *Johnson, J.F., The Highway Magazine, Dec., 1953.*
6. **Probable Life of Pipe Culverts,** *Mueller, R.L., Eng. News-Record, Vol. 155, Sept., 1955.*
7. **Underground Corrosion,** *Romanoff, M., Circ. 579, Nat'l. Bur. of Standards, Washington, D.C., April, 1957.*
8. **Several Recorded Installations of Metal Pipe Encased in Slag Concrete or Embedded in Slag Aggregate,** *Nat'l, Slag Assn., Circular Letter 28-60, Sept. 9, 1960.*
9. **Bacterial Activity at the Bottom of Back-Filled Pipe Line Ditches,** *John O. Harris, Corrosion, National Association of Corrosion Engineers, 1960.*
10. **Structural Considerations and Development of Aluminum Alloy Culvert,** *Koepf, A.H., HRB Bulletin 361, 1962.*
11. **Durability of Concrete in Service,** *ACI, Proc., Vol. 59, No. 12, Dec., 1962.*
12. **Aluminum Pipeline Case History Data,** *NACE Committee T-2M Rept. Mater. Protec., 1963.*
13. **Method of Predicting Long Term Corrosion Damage of Underground Metal Pipes,** *Cikerman, L.J., Gazavoe Delco No. 4, 1963.*
14. **Concrete Pipe Highway Culvert Survey,** *American Concrete Pipe Association, 1963.*
15. **Microbiological Studies Reveal Significant Factors in Oil and Gas Pipeline Back-Filled Ditches,** *Dr. J.O. Harris, Kansas State University, Dec., 1963.*
16. **Corrosion Performance of Aluminum Culvert,** *Lowe, T.A. and Koeph, A.H., Highway Research Bulletin No. 56, Highway Res. Board, 1964.*
17. **Report on Inspection of Bituminous Coated and Uncoated Galvanized Metal Culvert Pipe,** *Welborn, J.Y. and Olsen, R.E., Bureau of Public Roads, Oct., 1964.*
18. **Five Years Field Corrosion Study of Steel Pipe to Determine Effects of Backfill Materials,** *E.W. Baumann and D.W. Lewis, Hwy. Res. Record No. 140, 1966.*
19. **Soil Resistivity as Related to Underground Corrosion and Cathodic Protection,** *Schwerdtfeger, W.J., Hwy. Res. Record No. 110, 1966.*
20. **Symposium on Effects of Aggressive Fluids on Concrete,** *Hwy. Res. Record No. 113, 1966.*
21. **Methods of Estimating Corrosion of Highway Culverts by Means of Polarization Curves,** *R.J. Lendberg, Hwy. Res. Record No. 204, 1967.*
22. **Combatting Sulfate Attack on Concrete on Bureau of Reclamation Project,** *Bellport, B.P., U.S. Bureau of Reclamation, presented at symposium sponsored by Div. of Bldg. Res., Nat'l Res. Council of Canada & ACI, Toronto, April 7, 1967.*
23. **Control of Pipeline Corrosion,** *Peabody, A.W., Nat'l Assn. of Corrosion Eng., Houston, Dec., 1967.*
24. **Unexpected Corrosion of Galvanized Corrugated Metal Culverts,** *L.M. James, 4th Conference, Australian Road Research Board, Vol. 4, Pt. 2, 1968.*
25. **Performance of Ductile Iron Pipes in Soils,** *Romanoff, M., National Bureau of Standards, 1968.*
26. **Culvert Design in Some European Countries,** *Karadi, G.M. and Krizek, R.J., Hwy. Res. Board Record 262, 1969.*
27. **Corrosion Evaluation of Aluminum Culvert Based on Field Performance,** *T.A. Rowe, R.H. Vaterlaus, R.J. Lendberg and L.R. Lawrence, Hwy. Res. Record 262, 1969.*
28. **The Mechanisms of Abrasion of Aluminum Alloy Culvert, Related Field Experiences, and Methods to Predict Culvert Performance,** *A.H. Koepf, Research Record No. 262, 1969.*

29. **Control of Infiltration and Inflow Into Sewer Systems,** *Environmental Protection Agency, Dec., 1970.*
30. **Rational Structural Analysis and Design of Pipe Culverts,** *Krizek, R.J., Parmelee, R.A., Kay, J.N., NCHRP No. 116, 1971.*
31. **Comparative Study of Coatings on Corrugated Metal Culvert Pipe,** *David K. Curtice and John E. Funnell, Southwest Research Institute, U.S. Steel Corp., March 15, 1971.*
32. **Steel Products for Culvert Applications,** *Swan, J.D., Paper presented at 51st Annual Meeting of HRB, Jan., 1972, unpublished.*
33. **Corrugated Metal Pipe Study - Corps of Engineers (Omaha Report),** *Corps of Engineers, 1975.*
34. **Corrosion Behavior of Galvanized Sheet in Relation to Variation in Coating Thickness,** *C.E. Bird, Pretoria, South Africa, 1976.*
35. **Study of Corrosion of Corrugated Steel Pipe Spillways in Structures Designed by the Soil Conservation Service,** *Soil Conservation Service, 1978.*
36. **Corrugated Metal Pipe Durability Guidelines,** *Federal Highway Administration Technical Advisory T5040.2, 1978.*
37. **Anticipated Life of Zinc Coatings in the Atmosphere,** *Advertisement, St. Joe Zinc Company, Civil Eng. Magazine, Dec., 1978.*
38. **Evaluation of Highway Culvert Coating Performance, Federal Highway Administration,** *Report No. FHWA/RD-30-059, June, 1980.*
39. **Corrosion Performance of Metallic Coated Steel Culvert,** *Wheeling Pittsburgh Steel Corporation, Metallurgical Engineering Laboratory, 1980.*
40. **How Long Can Metal Culverts Last?,** *American City & County Magazine, 1980.*
41. **A Literature Study of the Combustion Hazards of PVC and ABS,** *University of Calgary, 1981.*
42. **An Opinion Report on the Utilization of Corrugated Aluminum Pipe as a Storm Sewer,** *Richard F. Stratfull, 1981.*
43. **Focus on External Corrosion,** *American Concrete Pipe Association, 1981.*
44. **Report on the Condition of Two-Year Old PVC and Concrete Sewers in Sweden,** *P. Svenshammar, Swedish Concrete Pipe Association, 1982.*
45. **Purdue University Evaluation of Out-of-Roundness Tolerances,** *Purdue University, 1982.*
46. **What Type Sewer Pipe is Best? Life-Cycle Cost Analysis Yields Answer,** *Civil Engineering Magazine, Oct., 1982.*
47. **New Threat to Public Health and Safety,** *Plastic Pipe, May 12, 1982.*
48. **Buried Fact No. 1 - Fires in Sewers and Culverts,** *American Concrete Pipe Association, May, 1982.*
49. **Rerounding of PVC Sewer Pipe,** *National Clay Pipe Institute, 1982.*
50. **Tucson Verifies Pipe's Durability,** *David Johnson and Jon Schladweiler, Public Works Magazine, December, 1982.*
51. **Literature Review of Potential Hazards to Human Health of Using PVC and CPVC Pipe for Potable Water Distribution,** *Southern Research Institute, February, 1983.*
52. **A Review of the Maine Department of Transportation Report "Durability of Drainage Structures,"** *Richard F. Stratfull, March, 1983.*
53. **Bacterial Corrosion of Steel Culvert Pipe in Wisconsin,** *Robert Patenaude, Transportation Research Record 1001, 1984.*
54. **Field Performance of Protective Linings for Concrete and Corrugated Steel Pipe Culverts,** *John O. Hurd, Transportation Research Record 1001, 1984.*
55. **Field Performance of Concrete and Corrugated Steel Culverts and Bituminous Protection of Corrugated Steel Pipe Culverts,** *John O. Hurd, Transportation Research Record 1001, 1984.*
56. **Precast Concrete Pipe Durability, State-of-the-Art,** *Mike Bealey, Transportation Research Record 1001, 1984.*
57. **Overview of Polymer Coatings for Corrugated Steel Pipe in New York,** *Robert M. Pyskadlo and Wallace W. Renfrew, Transportation Research Record 1001, 1984.*
58. **Metal Loss Rates of Uncoated Steel and Aluminum Culverts in New York,** *Peter J. Bellair and James P. Ewing, Transportation Research Record 1001, 1984.*
59. **Culvert Durability: Where Are We?,** *George W. Ring, Transportation Research Record 1001, 1984.*
60. **Aluminized Steel Culvert Pipe - Grandview-Mayfair Project,** *Metallurgical Engineering of Indiana, Inc., May 16, 1985.*
61. **Field Performance of Concrete Pipe Culverts Acidic Flow Sites in Ohio,** *John Owen Hurd, Transportation Research Record 1008, 1985.*
62. **Review of Specifications for Buried Corrugated Metal Conduits Installation,** *Ernest T. Selig, Transportation Research Record 1008, 1985.*
63. **Field Performance of Corrugated Polyethylene Pipe Culverts in Ohio,** *John O. Hurd, Transportation Research Record 1087, 1986.*
64. **An Investigation of Field Performance of Reinforced Plastic Mortar Pipes,** *Jey K. Jeyapalan, Wesley E. Saleria, Michael Thiyagaram and B.A. Magid, American Society of Civil Engineers, "Pipeline Infrastructure" proceedings, 1988.*
65. **Evaluation of Metal Drainage Pipe Durability After Ten Years,** *W.H. Temple and S.L. Cumbaa, Transportation Research Record 1087, 1986.*
66. **Durability Considerations - Precast Concrete Pipe,** *M. Bealey, ACI Concrete Durability Conference, 1987.*
67. **Pipe/Soil Stiffness Ratio Effect on Flexible Pipe Buckling Threshold,** *K.K. Kienow and R.C. Prevost, ASCE Pipeline Infrastructure Conference, June, 1988.*
68. **Inspection of Under Bridge Length Culverts,** *John M. Kurdziel, ASCE Pipeline Infrastructure Conference, June, 1988.*
69. **An Investigation of Field Performance of Reinforced Plastic Mortar Pipe,** *J.K. Jeyapalan, et. al., ASCE Pipeline Infrastructure Conference, June, 1988.*
70. **Culvert Durability Rating Systems,** *J.M. Kurdziel, Transportation Research Record 1191, 1989.*