

NCHRP

SYNTHESIS 303

**NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM**

Assessment and Rehabilitation of Existing Culverts

A Synthesis of Highway Practice

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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NCHRP SYNTHESIS 303

**Assessment and Rehabilitation of
Existing Culverts**

A Synthesis of Highway Practice

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Bridges, Other Structures, Hydraulics and Hydrology, Materials and Construction, and Maintenance

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in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD — THE NATIONAL ACADEMIES

WASHINGTON, D.C.
2002

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

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The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

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Project 20-5 FY 1999 (Topic 31-03)
ISSN 0547-5570
ISBN 0-309-069203
Library of Congress Control No. 2002109707
© 2002 Transportation Research Board

Price \$15.00

NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

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The Transportation Research Board evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

and can be ordered through the Internet at:

<http://www.nationalacademies.org/trb/bookstore>

Printed in the United States of America

PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

*By Staff
Transportation
Research Board*

This synthesis report will be of interest to department of transportation, county, and municipal engineers, as well as to other transportation professionals who are concerned with the condition and maintenance of buried culverts and storm sewers. Its objective is to determine the state of the practice of pipe assessment, the selection of appropriate repair or rehabilitation methods, and the management aspects of a pipe program. This report provides information on plastic, concrete, and metal pipes and their appurtenances, including inlets, manholes, joints, and headwalls. It also provides information on how transportation agencies have incorporated pipe assessment and corrective work (repair or rehabilitation) into a pipe management system and eventually into the larger transportation management system. Rehabilitation specifications and methods of field report are presented as well. The study presents what management systems and methods are being used by transportation agencies to predict the service life of pipes.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This report of the Transportation Research Board contains information derived from survey responses from 39 state transportation agencies (including Guam and Puerto Rico), 21 federal agencies, and 15 localities, including county road commissions, public works departments, and county engineering departments. In addition, a literature search was conducted to determine the current state of the practice.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the available information was assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the author's research in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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ACKNOWLEDGMENTS

David C. Wyant, DW Enterprises, Crozet, Virginia, was responsible for collection of the data and preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Josh Beakley, Director of Technical Services, American Concrete Pipe Association; Umakant Dash, Bridge Q & A Engineer, Pennsylvania Department of Transportation; James B. Goddard, Chief Engineer, Advanced Drainage Systems, Inc.; James J. Hill, Structural Design Engineer, Minnesota Department of Transportation (retired); Michale G. Katona, Professor/Chair, Department of Civil and Environmental Engineering, Washington State University; Stephen F. Maher, Senior Program Officer, Transportation Research Board; Shawn A. McLemore, H.W. Lochner, Inc., Tallahassee, Florida; John D. O'Fallon, Bridge Research Engineer, Turner Fairbank Highway Research Center, Federal Highway Administration; Brian C. Roberts, Executive Director, National Corrugated Steel Pipe Association; Philip L. Thompson, Senior

Hydraulics Engineer, Federal Highway Administration, U.S. Department of Transportation; and Martin Van Zandt, Deputy District Director, Maintenance and Operations, California Department of Transportation.

This study was managed by Jon Williams, Manager, Synthesis Studies who worked with the consultant, the Topic Panel, and the Project 20-5 Committee in the development and review of the report. Assistance in project scope development was provided by Donna L. Vlasak, Senior Program Officer. Don Tippman was responsible for editing and production. Cheryl Keith assisted in meeting logistics and distribution of the questionnaire and draft reports.

Crawford F. Jencks, Manager, National Cooperative Highway Research Program, assisted the NCHRP 20-5 Committee and the Synthesis staff.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance are appreciated.

ASSESSMENT AND REHABILITATION OF EXISTING CULVERTS

SUMMARY

The deterioration of pipes and culverts is a growing problem for transportation agencies. As transportation drainage infrastructures age, the need for repair or rehabilitation often becomes more critical. As a result, the number of pipes and culverts being repaired or rehabilitated is increasing each year.

Transportation agencies have more pipes and culverts than bridge structures in their transportation systems. (Throughout this report, the term “pipes” refers to both pipes and culverts.) The investment in and the importance of these pipes in the overall transportation system are substantial. Most pipes, however, are not seen by the traveling public and become noticeable only when a problem arises, such as settlement in the roadway or flooding. Occasionally there is an accident because an unexpected pipe failure, causes a large settlement in the road surface. A less frequent but important problem that can be caused by a failed pipe is pollution leaking into the surrounding soil. These potential pollutants can be lost through the joints of a pipe and can enter the groundwater or attach on to the soil particles for extended periods of time.

The investment in these mostly unseen facilities can represent a significant portion of the total investment a transportation agency makes in the transportation system. When a pipe fails there can be additional associated costs as well; for example, the higher cost to a transportation agency of an unplanned activity and the associated costs to the traveling public with travel delay and possibly detour costs when partial or complete closure of a roadway is necessary.

An agency that monitors and inventories its pipes and knows their condition may benefit from the smaller pipe management costs that come from eliminating or significantly reducing the number of failures. Also, the traveling public will benefit from a pipe management system because traffic delays and the occasional accidents because of a failed pipe are minimized.

Guidelines need to be developed and implemented to systematically track and assess the condition of pipes over time. The data collected during these assessments should be kept in a pipe management system for better management of all pipes, scheduling of maintenance activities, justification of funding needs, prioritization of pipe work, and any other analysis that may arise.

This synthesis study was initiated to determine the state of the practice of pipe assessment, the selection of appropriate repair or rehabilitation methods, and the management aspects of a pipe program. The study reports on information collected regarding the state of the practice for plastic, concrete, and metal pipes and their appurtenances, such as inlets, outlets, joints, access holes, junction boxes, wingwalls, endwalls, and headwalls. It also

provides information on how transportation agencies have incorporated pipe assessment and corrective work (repair or rehabilitation) into a pipe management system and eventually into the larger transportation management system. Rehabilitation specifications and methods of record keeping of field reports are presented as well. The study determines what management systems and methods are being used by transportation agencies to predict the service life of pipes.

A questionnaire was developed to survey local, state, and federal transportation agencies. The questionnaire requested information about each agency's inspection program, maintenance program, record keeping, material specifications, service-life predictions, management system, and guidelines for assessment, repair, and rehabilitation. In addition to the questionnaire, transportation agencies were requested to provide documents related to the questions asked in the survey; that is, data forms, inspection reports, specifications, and guidelines.

A second means of determining the state of the practice for this synthesis was through literature searches. From these searches, guidelines, methodologies, management systems, and service-life requirements of pipes used by transportation agencies and others were also discovered. The literature searches were used to locate additional information and, in some cases, provided more detail on the information received from the questionnaire responses.

Agency guidelines for pipe assessment vary from none to a comprehensive system. A limited number of transportation agencies have guidelines that range from a single page to a fully documented system. The Pennsylvania, California, Minnesota, and North Carolina Departments of Transportation (DOTs) and the Harford County (Maryland) Department of Public Works have one-page forms for collecting pipe data. The Connecticut, Maine, and New York State DOTs and the Maryland State Highway Administration have more extensive pipe programs. Maine's program presently supplies its data to a centralized pipe database that can be accessed from headquarters over their computer network. This database is being proposed as a data subset in the Maine DOT's data warehouse, which is under development. The ultimate goal is to have the data warehouse be the major data source for their transportation management system, the Transportation Integrated Network Information System. This system would allow management and maintenance personnel to perform analyses not possible several years ago and be more proactive, rather than reactive, in their pipe management program. In the interim, however, the centralized pipe database is the most inclusive data source for pipes in the DOT. Similar strategies to mitigate all transportation data, including pipe data, into a data warehouse for use in a larger transportation management system enterprise are being implemented in other states.

Most of the transportation agencies surveyed do not have methods to select types of pipe repair. The type of repair is dictated by the pipe defect and the experience of the repair personnel. In rehabilitation work, the only method used by some states is the service-life–durability relationship.

Transportation agencies have developed or borrowed charts from other agencies for factors such as pH, resistivity, and thickness of pipe. Most local agencies use their respective state DOT's charts, specifications for rehabilitation, and guidelines for assessment if they pursue a pipe management system. The Local Technical Assistance Program (LTAP) of the FHWA has developed a culvert management system (CMS) for local governments that could be used by local agencies and others for guidance in establishing a pipe program. None of the responding agencies, however, including the local agencies, indicated that they

used this product in their work. A manual, field guide, training course, and computer software program were produced by the LTAP for the CMS. The computer program contains five modules (inventory, condition, work needs, work funding, and schedule) and covers all the elements of a pipe program. Each module has a flow diagram and the data forms needed for successful completion. The other essential supporting program documents are included in the CMS: a manual with the details and background information, a guide for fieldwork, and a training course for the users of the system.

Very few agencies keep records on pipe conditions. When a preventative maintenance program is established, the records should become a part of the program and be kept for verification and history tracking. These records can be used to determine the rate of deterioration of a pipe, aid in the frequency of scheduling inspections, and assist in determining the appropriate time to repair or rehabilitate a deteriorating pipe.

The findings from this study suggest the following:

- That the establishment of a preventative maintenance program would help transportation agencies manage the pipes in their systems.
- That the data collected from the assessments could be stored in, at a minimum, a centralized pipe database, so that users would have access to the data for decision making.

In addition to the maintenance program and a centralized database, specifications are needed so that contractors will understand the requirements and what is expected during pipe repair or rehabilitation work. Most transportation agencies currently use construction specifications that are developed to address issues and requirements when a pipe is installed in an open cut. However, when a pipe is lined (trenchless pipe rehabilitation), the requirements, issues, and processes are different and require a different set of specifications that are specific for this type of work. At a minimum, the agency could use ASTM Specification A979/A979M-97, *Standard Specification of Concrete Pavements and Linings Installed in Corrugated Steel Structures in the Field*, as a guide for lining a pipe.

The pooling of funds by agencies to develop a comprehensive pipe management system may also be useful. A comprehensive pipe management system might include guidelines and photographs for inspection, frequency of inspections, standard data forms, guidelines for determining the appropriate corrective action (repair, rehabilitation, or replacement), record-keeping procedures, analysis methods for determining pipe condition or deterioration rate, and the economic analysis of the action to be taken. If an agency used such a system, it would be managing the system (proactive) rather than being at the mercy of the system (reactive). To develop this system without one state being unduly financially burdened, a number of states could pool their funds and share the cost of development. One agency could be responsible for the administrative and day-to-day operations of the project and coordinate the project activities with a consultant. An estimate of the cost of the project would need to be determined, so that each state could share equally in the cost. At the conclusion of the project each agency would have the latest technique and a system ready for implementation as described in the final report.

INTRODUCTION AND RESEARCH APPROACH

BACKGROUND

Within their transportation systems, transportation agencies are responsible for more pipes and culverts than bridge structures. (Throughout this report, the term “pipes” refers to both pipes and culverts.) The investment and importance of pipes in the overall transportation system are enormous. Unlike in the case of bridges, the traveling public is not aware of most of these pipes because they are situated at the bottom of slopes and, in some cases, under deep fills. The location and condition of these pipes becomes noticeable only when a problem arises, such as settlement in the roadway, flooding, etc. In 1978, transportation agency investment in these mostly unseen facilities was estimated to be approximately 10% of the total cost of the transportation system operations (*NCHRP Synthesis of Highway Practice 50* 1978). Currently, more than 20 years later, it is estimated that this cost could exceed that amount.

In addition, there are associated costs to the transportation agency (e.g., the higher cost of an unplanned activity once a pipe fails) and to the traveling public (e.g., travel delay and possibly detour costs) with the partial or complete closure of a roadway because of a pipe failure. Therefore, with the total cost to all parties potentially higher than most people realize, transportation agencies could benefit from the regular inspection of pipes and the assessment of their condition that could help minimize failures and reduce costs. To support the better management and analysis needed to accomplish such a proactive effort, pertinent data should be kept in an accessible and user-friendly pipe management system, which can allow the agency decision makers to perform analyses related to their work responsibilities.

As the frequency and rate of deterioration of pipes increases, because of their increasing age of service and the changing nature of watersheds that drain to them, the benefits of a proactive pipe system may exceed the cost of implementation. As the years of service increase, the wear and tear on the pipe increases because of physical actions such as abrasion, chemical actions due to environmental changes in the watershed, and changes in material properties due to aging. Any of these changes can cause an increase in the deterioration rate of the pipe and trigger a need for repair or rehabilitation before the planned service life is reached.

In the 1980s and 1990s, in an attempt to improve the pipe management, several agencies studied and evaluated the design methods used to determine the structural capacity of pipes constructed of various types of materials (Chambers et al. 1980; Mathioudakis and Agarwal 1996; Goble 1999; McGrath and Sagan 2000). Most of these evaluations were needed because new pipe materials and larger diameter pipes with a low bending stiffness and a smaller cross-sectional area were being introduced into the industry. Of equal importance, where resources allow, would be an inspection program for determining the condition of an installed pipe and/or its rate of deterioration, as well as the inclusion of these data into a pipe management system, such as those in use in Pennsylvania, California, North Carolina, and Maine.

Transportation agencies generally have in place systems to manage pavements, bridges, and signs. They have also developed and studied replacement and rehabilitation procedures for pavements and bridges. Examples of these systems for secondary and local roads are described in *NCHRP Report 222: Bridges on Secondary Highways and Local Roads—Rehabilitation and Replacement* (1980) and *NCHRP Report 243: Rehabilitation and Replacement of Bridges on Secondary Highways and Local Roads* (1981). These repair and rehabilitation procedures are usually part of a larger management system. Correspondingly, the establishment of a pipe management system by an agency would enhance the overall transportation system and give the agency better control of its overall operations. Data from inspection reports, including the final construction inspection report, could be analyzed as part of the pipe management system.

Without a robust pipe management system, proper maintenance, and scheduling of inspections, it is more difficult to perform repairs or rehabilitation in a timely and proactive manner. In other words, there is an increased likelihood that a pipe will deteriorate to such an unsatisfactory state that the riding surface of the road will dip or, worse, fail completely, and repair or rehabilitation of the pipe will need to be done immediately. An established pipe management system would provide an agency with a definitive methodology that could be used to justify the funding needed for pipes, assist the decision maker in determining the options available for repair or rehabilitation, and be beneficial for proper pipe maintenance.

To have a fully functional system, an inventory of all pipes, an assessment methodology, initial and periodic assessments, options for repair or rehabilitation, and linkage into a larger management or executive system need to be established. Several years ago, the National Association of Sewer Service Companies (NASSCO) realized the importance of a fully functional system and in response developed their *Manual of Practices* (NASSCO 1996). This document covers methods of gathering data, guidelines for using inspection cameras, assessment of conditions, defect rating codes, modeling, rehabilitation methods, materials, and life-cycle and least-cost analyses. Recently, the FHWA, through the Local Technical Assistance Program (LTAP), developed a culvert management system (CMS) for local governments to provide guidance and direction to local agencies and others in implementing a pipe management program (Thompson 2000). A manual containing background information and the details of the system was published. In addition, a field manual was created to aid the pipe inspector during the evaluation. A training course was developed to familiarize all personnel involved with the pipe program and specifically the CMS. The final product of the CMS is a computer software program designed to expedite the implementation process. The computer program contains five modules with flow diagrams and data forms: inventory of the culverts, condition and ratings, work needs (repair or rehabilitation), work funding and prioritization, and scheduling (time of the year and whether in-house or contract).

A related topic to the subject of this synthesis is pipe durability, which is discussed in Appendix F.

PURPOSE AND SCOPE

This study was initiated to determine the state of the practice in pipe assessment and in the selection of appropriate repair and/or rehabilitation methods. In addition, the study was undertaken to determine how pipe assessment and corrective work fit into the larger transportation management system and what efforts, research or otherwise, are needed to implement a pipe management system. This synthesis had the following six objectives:

1. To determine what guidelines were being used by transportation agencies to assess the conditions of pipes.
2. To determine what guidelines were being used to select the methodology to repair or rehabilitate a damaged pipe.
3. To determine what methods were being used to store inspection and maintenance records.
4. To determine what management systems were being used with an agency's assessment program.

5. To determine what methods were being used by agencies to predict the service life of pipes.
6. To determine what material specifications were being used during repair or rehabilitation of pipes.

The scope of this synthesis includes plastic, concrete, and metal pipes. System appurtenances such as inlets, outlets, joints, manholes, junction boxes, headwalls, endwalls, and wingwalls are included as well. Cast-in-place structures, box culverts, and bridges are not covered.

RESEARCH APPROACH

Two approaches were taken to achieve the study objectives: (1) a questionnaire was used to survey transportation agencies regarding their practices concerning pipe assessment and rehabilitation, and (2) a literature search was performed to determine the state of the practice.

Questionnaire

Organization

The questionnaire was kept short to make its completion easy for respondents and to maximize the number of responses. In addition, to make the respondent's role still easier, the questionnaire was primarily a "yes/no" survey and requested that copies of an agency's supporting documentation be returned with the survey. In general, the questionnaire requested information about the agency's inspection program, maintenance program, record keeping, guidelines for assessment, repair and rehabilitation, material specifications, service-life predictions, and management system. A copy of the questionnaire is provided as Appendix A.

The questionnaire was specifically structured to determine how an agency does pipe assessments, what the agency does with the data collected from these assessments, and if the agency has a management system to incorporate the collected data. In addition, the questionnaire was designed to ascertain if guidelines were used to determine the method of repair or rehabilitation from the inspection data and any service-life data used by the agency.

The survey questions were designed to provide a logical approach to pipe assessments. First, as an overview of the survey approach, it was important to know if an agency had preventative and/or inspection programs. If programs were established within the agency, the frequency of the inspections and records and data kept were of interest. The questionnaire also asked if the agency had guidelines to assess pipe and appurtenance conditions

and, if so, were there additional guidelines to determine the best method of repair or rehabilitation. In addition, the questionnaire was used to determine if there were material specifications used to guide rehabilitation work and if the agency had methods for considering the service life of pipes in their decisions. The final area of interest on the questionnaire was whether the agency uses some type of management system to schedule future inspections, perform advanced analyses, and justify funding requests.

A total of 155 questionnaires were sent to various transportation agencies including all state departments of transportation (DOTs), as well as those in Puerto Rico, Guam, and the District of Columbia; a number of federal agencies; and a large number of localities, including county road commissions, county engineering departments, public works departments, county utility departments, and park and recreation departments. A list of respondents is provided in Appendix B.

Rate of Return

The rate of return from state DOTs (including Guam and Puerto Rico) was 75% (39 of 52). Localities (including the District of Columbia) returned 40% (15 of 38) and federal agencies 32% (21 of 65). The return rate for all agencies was 48% (75 of 155). Several agencies also provided supporting documents. Details of the responses are reviewed in the following chapters.

Literature Review

Several keyword searches were done using TRIS, the Transportation Research Information Services, TRB's bibliographic transportation database. Other searches were conducted through AASHTO, the University of Virginia's public library, and the Internet. Information discovered during these searches covering guidelines, methodologies, management systems, and the service life of pipes is discussed in subsequent chapters.

ORGANIZATION OF SYNTHESIS

This synthesis is organized into five chapters (including this introduction) and six appendixes. Chapters 2 and 3 cover the methods used by transportation agencies to assess pipe conditions and select pipe repair or rehabilitation methods. Chapter 4 discusses the management systems used in pipe programs, the issue of record keeping with regard to inspection and preventive maintenance data reports, and the material specifications used during pipe rehabilitation work. Chapter 5 summarizes the synthesis findings and suggests areas where further action can be taken. Appendix A is the questionnaire and Appendix B provides the names and addresses of the respondents. Appendixes C, D, and E contain supporting documents, specifications, and examples of pipe guidelines provided by several respondents. Appendix F is an added section on pipe durability.

METHODS TO ASSESS PIPE CONDITION

To determine whether a pipe needs to be repaired, rehabilitated, or replaced, a thorough pipe inspection needs to be conducted and a report of the findings needs to be recorded. The first step in a pipe inspection program is to establish a standard set of guidelines, under which all inspectors will perform inspections in the same manner and the data will be consistently collected. To ensure a clear understanding of these guidelines and what is expected of the inspector, pipe inspectors should be trained in the use of the guidelines, the data that are to be collected, and how the data are to be used in the analysis of pipe conditions. Also, the inspector should be trained to identify defects, to identify the severity of the defects, and to complete the inspection reports essential to the record keeping.

Another element important to a successful pipe inspection program is a regular inspection schedule, similar to that provided in the National Bridge Inspection Standards (NBIS). NBIS structures are inspected on a 2-year cycle according to NBIS regulation 23 CFR 650.305. There is no national standard inspection schedule for pipes similar to the schedule for NBIS structures. Results from the survey confirmed that there is no standard state and local inspection cycle being followed by transportation agencies.

Ring (1984) suggested that major pipes be inspected at least every 3 years and more often where conditions are harsh. In 1986, the FHWA required that inspections be performed once every 2 years rather than every 3 years (Arnoult

1986). However, the FHWA allows states to perform less frequent inspection of NBIS structures on a case-by-case basis if justified. If conditions are mild where the structure is installed, the reporting agency can perform the inspection every 4 years with FHWA approval.

By establishing a regular inspection schedule for pipes, an agency could inspect individual on a different schedule when conditions warrant and guidelines established by the agency allow. This exception to the regularly scheduled inspection cycle would be similar to that outlined by the NBIS policy. An inspection cycle for pipes may also vary depending on the size of the pipe and the risk associated with the pipe location. In areas where there is brackish water, seawater, acidic runoff, or industrial discharge, the inspection cycle should be more frequent than normal. For example, the California Department of Transportation (Caltrans) performs inspections on larger pipes [those spanning more than 6.1 m (20 ft)] more frequently than on smaller pipes.

The survey of the transportation agencies also confirmed that the guidelines for minimum and maximum pipe size varies among agencies (Table 1). From these data, it appears that most agencies with guidelines try to inspect any pipe from a minimum of 305 mm (12 in.) to a maximum of 2.4 to 3.1 m (8 to 10 ft) in diameter. Most respondents (federal, state, and local) indicated that the size of the pipe to which the guidelines are applicable depends

TABLE 1
PIPE SIZE WITH GUIDELINES AS REPORTED BY AGENCIES

Pipe Material	Size Range	Opening Size of Pipes (inches)*							
		>12 <18	>18 <24	>24 <36	>36 <48	>48 <60	>60 <72	>72 <96	>96
Plastic	Minimum**	4			1				1
	Maximum***			1		1	1	2	1
Concrete	Minimum	5		2	2			1	2
	Maximum						2	2	4
Metal	Minimum	5		1	2			1	2
	Maximum					1	1	2	3

Notes: Table shows the number of responding agencies that had guidelines to inspect pipes. The number in each column is the number of agencies that define a minimum and a maximum size pipe with guidelines in their range of sizes at the top of the column. For example, there are four agencies with guidelines for plastic pipes as small as 12 to 18 in. There are also three agencies with guidelines for metal pipes larger than 96 in. Several agencies did not report a maximum size in their guidelines and several other agencies used a 20-ft span as their maximum; thus, no data were incorporated in the table. 1 in. = 2.54 cm.

*To determine the size range applicable to an agency's pipe guidelines, the minimum and maximum pipe openings were requested on the survey.

**Number of respondents indicating that this range of opening size is their minimum pipe size.

***Number of respondents indicating that this range of opening sizes is their maximum pipe size.

on the opening size, although a few agencies used the span parallel with the centerline of the roadway [Caltrans and the New York State Department of Transportation (NYSDOT)].

The majority of respondents indicated that they assessed appurtenances in addition to the pipe. Table 2 indicates that most of the transportation agencies (approximately 80%) with guidelines evaluate the ends of the pipe (inlets, headwalls, endwalls, and wingwalls) at the same time as the pipe inspection. An evaluation of the manholes and junction boxes is not included as often as an evaluation of the appurtenances at the ends of a pipe. Approximately 50% of the agencies that perform these evaluations include manholes and junction boxes in their guidelines. It stands to reason that the joints of a pipe and anything in that area need to be assessed in the evaluation as well as the end sections of pipes, because failures occur at locations other than the ends of pipes. Table 3 indicates the factors respondents consider in their guidelines. Other than corrosion, which is considered in a service life or durability determination, joint failure, deflection, and cracking are the three main factors of interest. As determined from the survey results and the literature search, most agencies are assessing the debris in the pipe, the scour at the ends of the pipe, the durability factors, and the physical deficiencies of the pipe.

TABLE 2
RESPONDENTS WITH APPURTENANCES INCLUDED IN GUIDELINES

Appurtenances	Response	
	Yes	No
Drainage Inlets	14	5
Manholes	8	11
Junction Boxes	7	12
Headwalls	17	2
Endwalls	17	2
Wingwalls	17	2

TABLE 3
FACTORS CONSIDERED IN PIPE ASSESSMENT AS REPORTED BY RESPONDENTS

Pipe Assessment Factors	Response	
	Yes	No
Hydraulic Capacity	8	10
Soil Conditions	6	13
Joint Failures	18	1
Corrosion	19	0
Wall Thickness	5	13
Deflection	18	1
Cracking	18	0

Note: Additional factors (siltation, clogging, debris, settlement, and scour) were used by respondents in pipe assessment, but were noted only a few times on the completed surveys.

A rating form for pipes that was modified by the FHWA from NBIS bridge inspections is shown as Figure 1 (Arnoult 1986). In addition to a condition rating for the pipe,

headwall, and wingwall, data about the condition of the channel, embankment, roadway shoulder, pavement, and waterway adequacy are requested on the FHWA rating form. The channel is rated to indicate the amount of scour, embankment erosion, siltation, etc. In addition, the inspector, using guides and photographs, rates the roadway shoulder, embankment, pavement, and alignment. The inspector is also asked to estimate the remaining life of the pipe and make recommendations and comments about the condition of the pipe. Without supporting documents, this is a difficult form to complete accurately. However, the FHWA's *Culvert Inspection Manual* (Arnoult 1986) does include supporting documents. These documents, including photographs, are essential to the inspector, ensuring that each input value is clearly understood and the data are collected consistently between inspectors at all locations. Without some guidance the inspector could not complete the form, because the condition rating values are not defined. Also, it would be difficult for the data collector to know how to determine the general rating value, including the estimated remaining life or appraisal of the pipe's structural condition, without some guides and supporting documents.

Only 15 respondents indicated having guidelines to assess pipe condition, whereas 44 respondents indicated that they had no guidelines (Table 4). As shown in this table, there is a higher percentage of state DOTs with guidelines (37%) than local agencies (33%) and federal agencies, such as U.S. Department of Agriculture Forest Service, U.S. Army Corps of Engineers, and Bureau of Indian Affairs (25%). The Utah DOT, Vermont Agency of Transportation, and most local agencies responding to the survey indicated that they use the guidelines suggested in FHWA's *Culvert Inspection Manual* (Arnoult 1986) (Tables 5 and 6). Because these guidelines pertain only to corrugated steel and concrete pipes, a need for guidelines for plastic pipes remains. For each rating in Table 5, a description of the shape, seams, joints, and metal is stated, so that the pipe inspector can properly rate the pipe. For concrete pipes the alignment, joints, and concrete are described for each rating (Table 6). A pipe, whether it is metal or concrete, gets a rating of 9 when first installed. As the pipe deteriorates over time the rating decreases in numerical value. Tables 5 and 6 also indicate that the road is closed to traffic only when the pipe rating has declined to 0 or 1.

The Pennsylvania DOT (PennDOT), Caltrans, North Carolina DOT (NCDOT), the Minnesota DOT (Mn/DOT), and Harford County Department of Public Works (Maryland) have one-page condition survey forms for collecting data on pipes. Examples of the PennDOT, Mn/DOT, and Harford County Department of Public Works forms are shown in Figures 2, 3, and 4, respectively. PennDOT's one-page form has many elements essential to a pipe management

LOCATION		
County _____ On Route _____	Division _____ At Kilometer Post _____	District _____ Or Km From _____
IDENTIFICATION	TYPE OF CULVERT	BARRELS
Culvert No. _____ Over _____	Shape _____ Material _____ Coating _____	Size _____ Number _____
CONDITION		
	<u>Condition Rating</u>	<u>Remarks</u>
Channel & Channel Protection		
Channel Scour	□	
Embankment Erosion	□	
Drift	□	
Silt	□	
Vegetation	□	
		General Rating <input type="text"/>
Culvert & Retaining Walls		
Barrel	□	
Headwall	□	
Wingwall	□	
Settlement	□	
Adequacy of Cover	□	
		General Rating <input type="text"/>
Estimated Remaining Life		
Inspectors Appraisal of Structural Condition (years)		<input type="text"/>
Roadway		
Shoulders	□	
Embankment	□	
Pavement	□	
		General Rating <input type="text"/>
APPRAISAL		
Waterway Adequacy		
Opening	□	
Alignment	□	
Scour	□	
		General Rating <input type="text"/>
Roadway Alignment		
Appraisers Estimate of General Rating		<input type="text"/>
Recommendations and Miscellaneous Comments		

FIGURE 1 FHWA modified rating form for pipes (Arnoult 1986).

TABLE 4
USE OF GUIDELINES TO ASSESS PIPE CONDITION

Guidelines*	Agencies					
	DOTs		Federal**		Local	
	Yes	No	Yes	No	Yes	No
Preventive Maintenance Program	10	26	5	6	3	9
Maintenance Records Kept	8	27	6	4	6	6
Inspection Program	22	13	6	4	9	3
Inspection Records Kept	14	10	6	3	7	5
Guidelines for Pipe Assessment	10	27	2	8	3	9
Guidelines for Repair Methods	2	34	1	10	2	7
Guidelines for Rehabilitation Methods	1	35	1	10	2	7
Material Specifications	22	15	3	7	6	4
Prediction of Service Life	7	28	4	5	2	9
Management System	7	30	1	9	3	7

*Column relates to questions on survey.

**Federal agencies include the U.S. Department of Agriculture Forest Service, Natural Resources Conservation Service, U.S. Army Corps of Engineers, Federal Lands Highway Division, Federal Aviation Administration, and FHWA.

system. The pipe, inlet, and outlet are rated according to the 10 keys at the bottom of form designed to assist in completing the evaluation for each pipe. The inspector also rates the outlet and parallel ditches as well as the amount

of ditch erosion during the evaluation of the pipe, using the keys to enhance consistency. To ensure accurate data on the condition of pipes and their appurtenances, PennDOT trains their inspectors in the proper use and understanding

TABLE 5
FHWA CULVERT INSPECTION RATING GUIDELINES FOR CORRUGATED METAL CULVERT BARRELS (Arnoult 1986)

Rating	Condition	Rating	Condition
9	<ul style="list-style-type: none"> • New Condition 	4	<ul style="list-style-type: none"> • <i>Shape</i>: marginal significant distortion throughout length of pipe, lower third may be kinked – <i>Horizontal Diameter</i>: 10 percent to 15 percent greater than design • <i>Seams or Joints</i>: Moderate cracking at bolt holes on one seam near top of pipe, deflection caused by loss of backfill through open joints • <i>Metal</i>: <ul style="list-style-type: none"> – <i>Aluminum</i>: extensive corrosion, significant attack of core alloy – <i>Steel</i>: extensive heavy rust, deep pitting
8	<ul style="list-style-type: none"> • <i>Shape</i>: good, smooth curvature in barrel <ul style="list-style-type: none"> – <i>Horizontal</i>: within 10 percent of design • <i>Seams and Joints</i>: tight, no openings • <i>Metal</i>: <ul style="list-style-type: none"> – <i>Aluminum</i>: superficial corrosion, slight pitting – <i>Steel</i>: superficial rust, no pitting 	3	<ul style="list-style-type: none"> • <i>Shape</i>: poor with extreme deflection at isolated locations, flattening of crown, crown radius 20 to 30 feet • <i>Horizontal Diameter</i>: in excess of 15 percent greater than design • 3 in. long cracks at bolt holes on one seam • <i>Metal</i>: <ul style="list-style-type: none"> – <i>Aluminum</i>: extensive corrosion, attack of core alloy, scattered perforations – <i>Steel</i>: extensive heavy rust, deep pitting, scattered perforations
7	<ul style="list-style-type: none"> • <i>Shape</i>: generally good, top half of pipe smooth but minor flattening of bottom <ul style="list-style-type: none"> – <i>Horizontal Diameter</i>: within 10 percent of design • <i>Seams or Joints</i>: minor cracking at a few bolt holes, minor joint or seam openings, potential for backfill infiltration • <i>Metal</i>: <ul style="list-style-type: none"> – <i>Aluminum</i>: moderate corrosion, no attack of core alloy – <i>Steel</i>: moderate rust, slight pitting 	2	<ul style="list-style-type: none"> • <i>Shape</i>: critical, extreme distortion and deflection throughout pipe, flattening of crown, crown radius over 30 feet – <i>Horizontal Diameter</i>: more than 20 percent greater than design • <i>Seams</i>: plate cracked from bolt to bolt on one seam • <i>Metal</i>: <ul style="list-style-type: none"> – <i>Aluminum</i>: extensive perforations due to corrosion – <i>Steel</i>: extensive perforations due to rust
6	<ul style="list-style-type: none"> • <i>Shape</i>: fair, top half has smooth curvature but bottom half has flattened significantly <ul style="list-style-type: none"> – <i>Horizontal Diameter</i>: within 10 percent of design • <i>Seams or Joints</i>: minor cracking at bolts is prevalent in one seam in lower half of pipe. Evidence of backfill infiltration through seams or joints • <i>Metal</i>: <ul style="list-style-type: none"> – <i>Aluminum</i>: significant corrosion, minor attack of core alloy – <i>Steel</i>: fairly heavy rust, moderate pitting 	1	<ul style="list-style-type: none"> • <i>Shape</i>: partially collapsed with crown in reverse curve • <i>Seams</i>: failed • <i>Road</i>: closed to traffic
5	<ul style="list-style-type: none"> • <i>Shape</i>: generally fair, significant distortion at isolated locations in top half and extreme flattening of invert <ul style="list-style-type: none"> – <i>Horizontal Diameter</i>: 10 percent to 15 percent greater than design • <i>Seams or Joints</i>: moderate cracking at bolt holes along one seam near bottom of pipe, deflection of pipe caused by backfill infiltration through seams or joints • <i>Metal</i>: <ul style="list-style-type: none"> – <i>Aluminum</i>: significant corrosion, moderate attack of core alloy – <i>Steel</i>: scattered heavy rust, deep pitting 	0	<ul style="list-style-type: none"> • <i>Pipe</i>: totally failed • <i>Road</i>: closed to traffic

Notes: Rating guidelines are for round or vertical elongated corrugated metal pipe barrels. See Coding Guide for description of Rating Scale. As a starting point, select the lowest rating that matches actual conditions.

of the forms. Mn/DOT’s one-page form rates the overall condition of the pipe as well as indicates the distresses or conditions discovered during inspection that should be checked during future inspections (Figure 3). These conditions or distresses include pitting, misalignment, spalling, siltation, scour, road stress, and voids in the road. The Harford County one-page form also captures other features (siltation, traffic barriers, and vegetation) in the vicinity of the pipe being inventoried and evaluated (Figure 4). The pipe’s condition is rated on a scale from 0 to 9, where 9 is new and 0 indicated no inspection was performed. The pipe is evaluated and rated on structural appearance, alignment, deflection, and separation of joints. The inspector also has space on the form to include any additional com-

ments. Harford County has converted this hard copy version to a form accessible by laptop computer.

NCDOT and the Saginaw County Road Commission have started the process of implementing a pipe management program. NCDOT is presently inventorying and rating all culverts statewide larger than 914 mm (36 in.), but smaller than NBIS structures. Pipes less than 914 mm (36 in.) in diameter are not being inventoried or inspected at this time. In addition to the general condition rating assigned in the initial assessment, the location, size, and length of each culvert will be collected and stored in an Access database. Photographs of each pipe will also be taken. These data will be entered on a form similar to the one shown in Figure 5.

TABLE 6
FHWA CULVERT INSPECTION RATING GUIDELINES FOR CONCRETE CULVERT BARRELS (Arnoult 1986)

Rating	Condition	Rating	Condition
9	<ul style="list-style-type: none"> • New Condition 	4	<ul style="list-style-type: none"> • <i>Alignment</i>: marginal; significant settlement and misalignment of pipe; evidence of piping; end sections dislocated, about to drop off
8	<ul style="list-style-type: none"> • <i>Alignment</i>: good, no settlement or misalignment • <i>Joints</i>: tight with no defects apparent • <i>Concrete</i>: no cracking, spalling, or scaling present; surface in good condition 		<ul style="list-style-type: none"> • <i>Joints</i>: differential movement and separation of joints; significant infiltration or exfiltration at joints • <i>Concrete</i>: cracks open more than 0.12 in. with efflorescence and spalling at numerous locations; spalls have exposed rebars which are heavily corroded; extensive surface scaling on invert greater than 0.5 in.
7	<ul style="list-style-type: none"> • <i>Alignment</i>: generally good; minor misalignment at joints; no settlement • <i>Joints</i>: minor openings, possible infiltration/exfiltration • <i>Concrete</i>: minor hairline cracking at isolated locations; slight spalling or scaling present on invert 	3	<ul style="list-style-type: none"> • <i>Alignment</i>: poor with significant ponding of water due to sagging or misalignment pipes; end section drop off has occurred • <i>Joints</i>: significant openings, dislocated joints in several locations exposing fill materials; infiltration or exfiltration causing misalignment of pipe and settlement or depressions in roadway • <i>Concrete</i>: extensive cracking, spalling, and minor slabbing; invert scaling has exposed reinforcing steel
6	<ul style="list-style-type: none"> • <i>Alignment</i>: fair, minor misalignment and settlement at isolated locations • <i>Joints</i>: minor backfill infiltration due to slight opening at joints; minor cracking or spalling at joints allowing exfiltration • <i>Concrete</i>: extensive hairline cracks, some with minor delaminations or spalling; invert scaling less than 0.25 in. deep or small spalls present 	2	<ul style="list-style-type: none"> • <i>Alignment</i>: critical; culvert not functioning due to alignment problems throughout • <i>Concrete</i>: severe slabbing has occurred in culvert wall, invert concrete completely deteriorated in isolated locations
5	<ul style="list-style-type: none"> • <i>Alignment</i>: generally fair; minor misalignment or settlement throughout pipe; possible piping • <i>Joints</i>: open and allowing backfill to infiltrate; significant cracking or joint spalling • <i>Concrete</i>: cracking open greater than 0.12 in. with moderate delamination and moderate spalling exposing reinforcing steel at isolated locations; large areas of invert with surface scaling or spalls greater than 0.25 in. deep 	1	<ul style="list-style-type: none"> • <i>Culvert</i>: partially collapsed • <i>Road</i>: closed to traffic
		0	<ul style="list-style-type: none"> • <i>Culvert</i>: total failure of culvert and fill • <i>Road</i>: closed to traffic

Notes: Rating guidelines are for precast concrete pipe culvert barrels. See Coding Guide for description of Rating Scale. As a starting point, select the lowest rating that matches actual conditions.

Mn/DOT and the Maine DOT (MDOT) compile the individual pipe conditions from their pipe feature report into a summary report. Table 7 is an example Mn/DOT's summary report showing the location, condition, and type of defects for each culvert. In addition to the survey form, Mn/DOT provides photographs to aid in the evaluation and visually based guidelines that do not require actual measurements of each pipe. In addition, observations are made at or near the ends of the pipe. An inspector indicates a distress or a condition in the field by placing a "Y" in the proper column on the summary report. This report lists all problem pipes as well as the milepost of the pipe, the pipe identification number, and the overall condition of the pipe.

For the smaller diameter pipes, only one respondent, the Alameda County (California) Public Works Agency, indicated that they used some means to inspect the interior of the pipe, other than visually checking at each end with a flashlight. Inspections from the end of a pipe are not a very accurate method for examining the interior of any length pipe. Alameda County uses a video camera with its own

light source to inspect the interior of their pipes. In addition, a number of DOTs and local transportation agencies, including those in Ohio, Oklahoma, Virginia, New Jersey, Delaware, Florida, Tennessee, Michigan, Kentucky, and California, are using video cameras in some inspections; that is, pavement edge drains and underdrains. Other DOTs are considering purchasing video cameras to enhance their inspection programs after seeing what benefits are being derived by the DOTs listed above. Caltrans has also started using video cameras to evaluate larger pipes in four of its districts as a pilot in a proposed statewide program to create a database of pipe conditions. By using a video camera, the agency can record inspections on tape, saving the records for later viewing, comparative analysis, and as the resource in deciding what corrective action to take (Figure 6). The Caltrans form provides data about the type of pipe, size and length of pipe, location of the pipe, pipe lining, invert of the pipe, rating values of seven conditions, and repair strategy with comments that can be related to the tape at a later time. At the top of the form Caltrans provides the inspector with keys and rating guides.

Location				
District:	1	Latitude:	45 48 12.22 N	
County:	Pine	Longitude:	95 59 24.65 W	
Roadway:	IS 35	Control Section:	5880	
Milepost:	168.20	Station Number:		
Direction:				
Description/Activity				
Date:	9/1/91	Cover:		
Activity:	Discover	No. of Joints:		
Shape:	Round	Rise:	18.00	Inches
Material:	Corrugated Metal (CMP)	Span:	18.00	Inches
Type:		Length:	76.0	Feet
Special Feature:				
Comments:	N.B.L. REPLACE			
Inspection				
Last Inspection:	9/1/91	Reason:	Scheduled Review	
Inspection ID:	758	Video Location:		
Condition:				
Overall:	3			
% Cond 1:	0	% Cond 3:	100	
% Cond 2:	0	% Cond 4:	0	
Inspection Flags:				
Clean:	Water:	Piping:	Misallan:	Inslope Cav:
Repair:	Plugged:	Spalling:	Joints Sep:	Road Stress: Y
Sign:	Silt:	Pitting: Y	Distress:	Road Void:
	Scour:	Holes: Y		
Comments: N.B.L. REPLACE				

FIGURE 3 Example of a completed Mn/DOT pipe feature report (Figure courtesy of Mn/DOT).

NYSDOT has an extensive culvert program including standardized forms for culverts smaller than NBIS structures. They define culverts as “structures that represent grade separation structures that have a total span distance measured along the centerline of the above roadway of twenty feet or less” (MacDougall 1991). NYSDOT has developed the *Culvert Inventory and Inspection Manual* that describes their culvert program. Instructions on completing

their culvert inventory and culvert inspection rating forms are provided to each culvert inspector (Figures 7 and 8). Figure 7 captures items of culvert identification including structural, safety, feature carried, and feature intersected for the inventory. Among the items gathered are drainage area, velocity of current, year built, sidewalks, and roadway approach width. With the inventory the inspector can then rate the different items of the roadway,

I. GENERAL INFORMATION

COUNTY NUMBER ROUTE ORIENT.

MILEPOINT ACROSS

CITY LOCATION

ROUTE CARRIED TOTAL FIELD TIME SYSTEM

INSPECTED BY REVIEW BY UPDATED BY

INSPECTION DATE REVIEW DATE LAST UPDATE DATE

II. STRUCTURE INFORMATION

YEAR BUILT YEAR REBUILT NC SKEW GRADE

TYPE AND MATERIAL TYPE COATING

DISTANCE BETWEEN BARREL HEIGHT CROWN TO BED

OF BARRELS BARREL WIDTH BARREL HEIGHT

LENGTH ALONG ROADWAY LENGTH ALONG CULVERT

APPROACH ROADWAY WIDTH WATER DEPTH COST

APPROACH SHOULDERS LEFT RIGHT STABLE

HEADWALLS: INLET OUTLET

III. CODING INFORMATION

STRUCTURE CONDITION PROMPT ACTION ISSUED?

ESTIMATED REMAINING LIFE SIGN NOTICE ISSUED?

SIGNS PRESENT

WORK REQUIRED:

CODE	<input type="text" value="0"/>	QUANTITY	<input type="text" value="0"/>	UNITS	<input type="text"/>
CODE	<input type="text" value="0"/>	QUANTITY	<input type="text" value="0"/>	UNITS	<input type="text"/>
CODE	<input type="text" value="0"/>	QUANTITY	<input type="text" value="0"/>	UNITS	<input type="text"/>
CODE	<input type="text" value="0"/>	QUANTITY	<input type="text" value="0"/>	UNITS	<input type="text"/>

General Comments

FIGURE 5 Example of a completed NCDOT non-NBIS inspection form (Figure courtesy of NCDOT).

TABLE 7
EXAMPLE OF A COMPLETED Mn/DOT SUMMARY REPORT (Courtesy of Mn/DOT)

Mn/DOT Hydraulic infrastructure pipes on IS 35, milepost 150.00 to 180.00															
MP	Pipe ID	Cond.	Repair	Water Plug.	Silt Piping	Spalling	Pitting	Misalign.	Joints Sep.	Holes	Distress	Inslp. Cav.	Rd. Void	Rd. Stress	Scour
163.50	2964	2							Y				Y		
163.60	3504	2							Y				Y		
163.60	3506	2							Y				Y		
163.80	2966	2							Y		Y				
164.10	2965	2											Y		
164.20	3947	2											Y		
164.20	3948	2											Y		
164.40	3667	2							Y				Y		
164.60	2806	2													
164.60	2819	2							Y		Y		Y		
164.60	3231	2													
164.70	3334	2							Y						
164.70	3351	2							Y						
164.70	3726	2											Y		
164.95	3626	2											Y		
165.20	3435	2							Y						
165.20	3446	2							Y						
165.40	3651	2											Y		
165.48	2619	2													
165.49	2410	2													
165.49	2628	2													
165.50	2632	2													
165.52	2631	2													
165.53	2284	2													
165.54	2659	2													
165.55	4006	3			Y				Y				Y		

Key: Plug. = Plugged
 Misalign. = Misalignment
 Joints Sep. = Joints Separated
 Inslp. Cav. = Inslope Cavitation
 Rd. Void = Road Void
 Rd. Stress = Road Stress.

structure, and channel (Figure 8). The main office of the DOT oversees regional office culvert repair programs and helps to reduce the number of deficient culverts by providing funds to the regional offices. Once each year the regional culvert inspectors rate each culvert. The low culvert inspection ratings (3 or 4) are then summarized into an annual culvert inspection requirements table (Table 8). This table then provides the decision makers at the regional and main offices with the necessary data to prioritize the pipes needing work.

The Connecticut DOT (ConnDOT) has an extensive program similar to NYSDOT with inventory and condition forms, classifications, instructions, photographs, and references. The inspector is also referred to three reports (Arnoult 1986; Ballinger and Drake 1995; AASHTO 1999) and ConnDOT’s *Bridge Inspection Manual* for guidance in completing the field documents.

A third state DOT with the elements of a pipe management system similar to those of NYSDOT and ConnDOT

is the Maryland State Highway Administration (MDSHA). MDSHA performs inspections on all pipes every 4 years. If a culvert has a poor rating at the 4-year cycle inspection, MDSHA increases the inspection frequency to 2 years, which is similar to FHWA guidelines.

MDOT has implemented a pipe management system that is a part of a larger system. Assets are located, identified, classified, and rated for their condition (*Inventory of Managed Assets . . . 1999*). The pipe management system has guidelines to explain each input value so that the trained evaluator can accurately complete the data entry sheet (see Appendix C). This manual also provides color pictures of assets in various conditions as references for the inspector (for more details see chapter 4).

MDOT identifies any drainage structures with a span width of less than 1.5 m (5 ft) that crosses beneath the travelway being inventoried by the inspector as cross culverts. Cross culverts have a different set of guidelines and entry form in the pipe management system (see Appendix

C U L V E R T I N V E N T O R Y C O D I N G

CONTROL ITEMS:

Region:	County:	CIN: C
---------	---------	--------

CULVERT IDENTIFICATION ITEMS:

Polit. Unit:	Owner:	
Maint. Resp.:	Cont. Plans Avail.?:	Hydr. Report Avail.?:
Orig. Contract #:	Year Built:	

STRUCTURAL ITEMS:

T.M.S.:	# of Spans:	Length of Max. Span:	Total Length:
Out-to-Out:	Abut. Height:	Depth of Cover:	
Abut. Skew Δ :	Roadway Approach Width:		
Curb-to-Curb:	Sidewalks:	Median:	
Abut. Type:	Abut. Wingwall Type:	Abut. Footing Type:	
Abut. Pile Type:	Abut. Jt. Type:	Abut. Slope Protection:	

SAFETY ITEMS:

Type of Appr. Rail:	Type of Culvert Rail:
Appraisal of Appr. Roadway Alignment:	

INSPECTION ITEMS:

Insp. Resp.:

POSTING ITEMS:

Posted Load:	Date Posted: / /
--------------	--------------------------

FEATURE CARRIED ITEMS:

Description or Route # and Refer. Marker:		
S.H. #:	Station: + :	Fed. Aid Sys.:
Funct. Class. :	# of Lanes on Culvert:	AADT:
Year AADT:	Avg. Daily Truck Traffic:	Bypass Detour Length:

FEATURE INTERSECTED ITEMS:

Description or Route # and Refer. Marker:		
Stream Bed Material:	Bank Protection:	Velocity of Current:
Drainage Area:	Design Storm Freq.:	Design Discharge 'Q':
Headwater Depth:	Slope:	

HM 1 (1/92)

FIGURE 7 NYSDOT culvert inventory form (MacDougall 1991).

CULVERT INSPECTION RATINGS

CONTROL ITEMS:

CIN: C

Insp. Type:

Date: / /

ROADWAY ITEMS:

Remarks:

<input type="checkbox"/>	Pavement:
<input type="checkbox"/>	Shoulders:
<input type="checkbox"/>	Guide Railing:
<input type="checkbox"/>	Settlement:
<input type="checkbox"/>	Embankment:
<input type="checkbox"/>	General Recommendation:

STRUCTURE ITEMS:

Remarks:

<input type="checkbox"/>	Abutment & Pier:
<input type="checkbox"/>	Span:
<input type="checkbox"/>	Headwall:
<input type="checkbox"/>	Wingwall:
<input type="checkbox"/>	General Recommendation:

CHANNEL ITEMS:

Remarks:

<input type="checkbox"/>	Opening:
<input type="checkbox"/>	Alignment:
<input type="checkbox"/>	Scour/Erosion:
<input type="checkbox"/>	Alluvium, Debris, Vegetative Growth:
<input type="checkbox"/>	General Recommendation:

GENERAL RECOMMENDATION

Overall and Additional Remarks:
.
.
.

Form Completed By:	Title:
--------------------	--------

HM 1 (1/92)
reverse

FIGURE 8 NYSDOT culvert inspection ratings form (MacDougall 1991).

TABLE 8
 NYSDOT ANNUAL CULVERT INSPECTION REPORT SHOWING CULVERTS WITH LOW RATINGS (Courtesy of NYSDOT)

1999–2000 Annual Culvert Inspection Requirements Condition Rating 3 or 4							
Reg	Culv. No.	Route	Ref. MKR1	CR Barrel	Length Max. Span	When	CR G
2	C220024	28	28 22091126	3	5	01/22/1997	3
2	C220027	28	28 22091194	4	18	01/13/1997	4
2	C220032	28	28 22091376	4	6	03/26/1996	5
2	C220042	030	030 22061388	4	10	04/11/1995	5
2	C220043	30	30 22061394	4	9	01/22/1997	4
2	C220050	30	30 22061652	4	8	01/22/1997	4
2	C220052	30	30 22061702	4	5	01/10/1997	4
2	C220082	10	1022051128	4	16.6	11/29/1994	4
2	C230047	8	8 23081172	3	5	10/31/1997	3
2	C230094	80	80 23051023	4	5	10/24/1997	4
2	C230095	80	80 23051026	4	5	10/29/1997	4
2	C240054	80	8024021087	4	9	03/06/1998	5
2	C250016	5	525121267	4	5.2	05/23/1996	5
2	C250020	5	525121295	4	13	06/03/1996	5
2	C250095	862	86225011014	4	8	12/24/1996	5
2	C260001	12	1224031000	4	5	01/05/1998	4
2	C260002	12	1224031010	4	5	01/05/1998	4
2	C260003	12	1224031011	4	5	01/05/1998	4
2	C260004	12	1224031013	4	5	01/05/1998	4
2	C260005	12	1224031014	3	5	01/05/1998	3
2	C260007	12	1224031071	3	5	01/05/1998	3
2	C260008	12	1224031078	4	6	01/05/1998	4
2	C260010	12	1224031082	4	11.6	02/28/1997	4
2	C260013	12	1226041006	4	10	01/05/1998	4
2	C260018	12	1226041053	3	10	01/06/1998	4
2	C260026	20	2026101005	4	8	01/06/1998	4
2	C260028	20	2026101051	4	5	02/28/1997	3

C). When the total flow area is less than 1.77 m² (19 ft²) for multiple culverts, the structure is classified and inventoried as a culvert. Entrance culverts, pipes under an entrance, and catch basins have similar inventory/condition definitions and data sheets, but are not included in this synthesis.

If the flow area exceeds 1.77 m² (19 ft²) or the span width is greater than 1.5 m (5 ft) but less than 3.05 m (10 ft) or any combination of pipes such that the total flow area is less than 7.4 m² (80 ft²), MDOT classifies those structures as struts. A trained inspector uses a separate set of guidelines to report on strut condition (see Appendix C).

In addition to those DOTs that are using standardized forms, almost every DOT produces short reports describing

the condition of pipes that are inspected on a case-by-case basis or describing the repair or rehabilitation technique used on a deteriorated pipe (Hixon 1992). Neither these reports nor the methods of inspection are standardized from site to site. The engineer or the report author was charged with assessing the pipe condition, determining the method of repair or rehabilitation (in some cases getting the corrective work done) and documenting the efforts. In almost all cases the engineer or the report author knew of no standard data or inspection form; therefore, the pipe's deficiencies were corrected according to individual standards and the necessary reports filed to complete the paperwork. There was no indication that any report documented any innovative solution or data collection or analyses from the Hixon report.

METHODS TO SELECT PIPE REPAIR AND REHABILITATION

PIPE REPAIR

Pipe repair is a maintenance activity that keeps a pipe in a uniformly good and safe condition. It can be scheduled as a routine maintenance activity or as an activity that requires immediate attention due to a reaction, such as a dip in the roadway, caused by a defect in the pipe (Figures 9 and 10). The repair activity can be patching, crack sealing, invert paving, lining, or joint work. If an agency undertakes preventative maintenance, the repair is generally scheduled as a result of a cyclic program. When a preventative maintenance program is established, light deterioration of a pipe can be corrected to avoid the development of more serious deterioration (Ballinger and Drake 1995). Table 9 shows the work options for different strategies, such as routine maintenance, preventative maintenance, rehabilitation, and replacement. For each strategy the objectives are different and at least two work options are available. For example, if management requests routine maintenance, then, using Table 9, the two work options are debris and sediment removal and thawing frozen culverts.

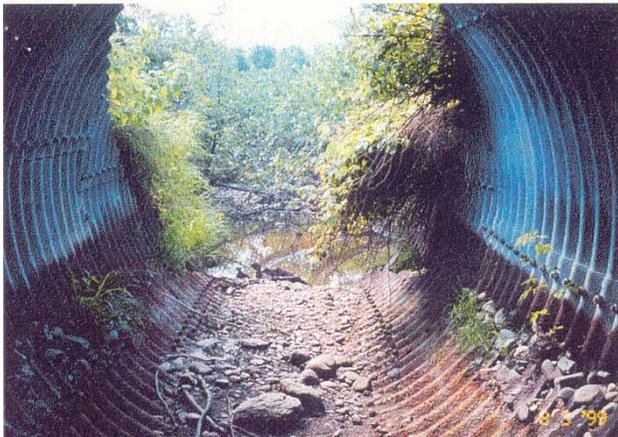


FIGURE 9 Soil and rock infiltrating into pipe (Figure courtesy of Maine DOT).

Only 9% of the survey respondents (5 of 56) had guidelines to select pipe repair methods (Table 4). The type of defect in the pipe indicates the problem with the pipe as well as, in most cases, the repair required. For example, if the bottom of a concrete pipe has deteriorated then invert paving may be sufficient to restore the pipe. The Alameda County Public Works Agency indicated in their response that the repair method to be used is determined from the observations during video inspection. Documents cited in



FIGURE 10 Bad seams that allow leakage and undermining of the backfill (Figure courtesy of Maine DOT).

the literature search confirm that agencies perform the repair as dictated by the defects discovered during pipe inspection (Hixon 1992; Ballinger and Drake 1995; Gift and Smith 2000).

Most repair efforts do not require a detour, bypass, or lane closure because the work does not affect the traffic flow. The only traffic control that may be required for repair work is directing traffic around vehicles parked on the shoulder of the roadway.

PIPE REHABILITATION

Rehabilitation of a pipe takes maximum advantage of the remaining usable pipe, so that the pipe is returned to its initial condition or better. In other words, the pipe is reconditioned and with technological improvements; that is, coatings. The condition of the rehabilitated pipe can be better than the condition of the original pipe when it was first installed. If a pipe exceeds the preventative maintenance stage, but is not at the point where the structural integrity is lost, then rehabilitation is the proper corrective action. If a pipe deteriorates to a point where (1) its structural integrity or soil support is lost; (2) insurmountable problems, such as scour or erosion of the streambed or soil mitigating through pipe joints, are occurring; or (3) the roadway over the pipe is lost (excessive deflection), then pipe replacement would be the appropriate corrective action (Ballinger and Drake 1995; Table 9).

Only 4 of 56 respondents (7%) indicated that they had guidelines to select a pipe rehabilitation method (Table 4).

TABLE 9
WORK OPTIONS FOR DIFFERENT PIPE STRATEGIES (Ballinger and Drake 1995)

Strategy	Objective	Work Options
Routine Maintenance	To keep a culvert in a uniform and safe condition by repairing specific defects as they occur.	<ul style="list-style-type: none"> • Debris and sediment removal • Thawing frozen culverts
Preventive Maintenance	A more extensive strategy than routine maintenance, intended to arrest light deterioration and prevent progressive deterioration.	<ul style="list-style-type: none"> • Joint Sealing • Concrete patching • Mortar repair • Invert paving • Scour prevention • Ditch cleaning and repair
Rehabilitation	Takes maximum advantage of the remaining unusable structure in a culvert to build a reconditioned culvert.	<ul style="list-style-type: none"> • Repair of basically sound endwalls and wingwalls • Invert paving • Repair of scour • Slope stabilization • Streambed paving • Addition of apron or cutoff wall • Improving inlet configuration • Installing debris collector
Upgrade to Equal Replacement	Upgrade to provide service that is equal to that provided by a new structure.	<ul style="list-style-type: none"> • Addition, repair, or replacement of appurtenant structures • Lining of the barrel • Provision of safety grates or safety barriers • Lengthening of the culvert
Replacement	Provide a completely new culvert with a new service life.	<p>Can be accompanied by:</p> <ul style="list-style-type: none"> • Realignment • Hydraulic structural and safety improvements • Change in culvert shape or material

TABLE 10
WYOMING PIPE SELECTION TABLE FOR CORROSION RESISTANCE (Courtesy of Wyoming DOT)

Type of Conduit	CR1	CR2	CR3	CR4	CR5	CR6
Galvanized Steel	Yes	No	No	No	No	No
Aluminum Coated Steel (Type II)	Yes	No	No	No	No	No
Bituminous Coated Galvanized Steel	Yes	Yes	No	No	No	No
Aluminum Alloy	Yes	Yes	Yes	Yes	No	No
Polymeric Precoated Galvanized Steel*	Yes	Yes	Yes	Yes	Yes	No
RCP Type II Cement	Yes	Yes	Yes	Yes	Yes	No
RCP Type V or Type II Modified Cement	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table is not applicable for structural plate pipe.
RCP = reinforced concrete pipe.

*Polymeric coating of 250 µm on both sides.

However, more respondents (15) indicated that they consider the following factors in their decision to rehabilitate a pipe: hydraulic capacity, traffic volume, height of fill, service life, and risk assessment. Service life was mentioned by 12 of these 15 respondents. Most agencies that consider service life use pH and resistivity, a measure of corrosion resistance, to determine the type of pipe material to be used. Some agencies keep their selection charts and criteria simple; for example, Wyoming, Arkansas, and Louisiana (Tables 10–12). The Montana DOT indicated that they changed their guidelines for service life when the FHWA published its report on Type II aluminized steel (Potter et al. 1991; see Table 13). Each of these state DOTs

have tried different ways to simplify their guidelines. Arkansas and Louisiana included the type of roadway in their charts, whereas Montana is the only DOT that factors in pH. Louisiana is also the only DOT that shows minimum design service life. However, NYSDOT and Caltrans use more complicated charts to determine the estimated service life of their pipes. NYSDOT predicts the anticipated service life by dividing the state into two zones, as defined in Table 14. Table 15 indicates the anticipated service life and Table 16 shows the ways that additional years can be gained through another coating on the pipe. This approach to increasing service life is very similar to the method suggested by the National Corrugated Steel Pipe Association.

TABLE 11
ARKANSAS PIPE CHART CORRELATING FACILITY AND MATERIAL TYPES TO PIPE
FUNCTION (Courtesy of Arkansas DOT)

Type Facility	Pipe Function	Material Type
Interstate	Cross drain	Concrete
	Storm sewer	Concrete
Arterial	Cross drain	Concrete
	Storm sewer	Concrete or smooth-lined polymer-coated CSP
Collector and Local	Cross drain	Concrete asphalt-coated CSP, aluminum-coated CSP, or polymer-coated CSP
	Storm sewer	Concrete or smooth-lined polymer-coated CSP
City Street*	Cross drain	Concrete or polymer-coated CSP
	Storm sewer	Concrete or smooth-lined polymer-coated CSP
All	Side drain	Refer to current specifications, section 606

Note: CSP = corrugated steel pipe.

*The city administration may select the type of culverts to be used on city streets in accordance with normal city policy.

Caltrans designs its pipes for a maintenance-free service life of 50 years using charts shown as Figures F1 and F2, and using Figure F3 as a guide to increasing the service life by applying different coatings to steel pipes (Appendix F).

Service life was factored into the decision process by 13 of 55 responding agencies (24%) (Table 4). Most agencies indicated that they use service-life data provided by the manufacturers. Service life is generally considered when metal pipes are used and a new pipe is inserted into the old, deteriorated pipe or the deteriorated pipe is replaced. Occasionally service life is a factor with concrete pipe (Utah DOT), but rarely with plastic pipe. The Nebraska Department of Roads indicated that they use the Caltrans method to predict the service life of their culverts. The two local agencies responding positively to the service-life questions indicated that they use their state DOT's service-life procedures.

Table 17 indicates the permanent methods of structural stabilization reported by the agencies responding to the questionnaire. Lining of the pipe is the method of stabilization preferred by most agencies (Figure 11). From the literature search, the most reported method of permanent structural stabilization is also lining. From the survey it was determined that cut-and-cover and invert paving are equally as popular, but are not the preferred method of stabilization of a deteriorated pipe (Figure 12). From the literature it was indicated that where states have been faced with insufficient funds to perform major or deep excavations, the roadway is paved, or the traffic volume is high, they have used invert replacement, insertion of a pipe in-

side the deteriorating pipe, or installation of some kind of lining to avoid cut and cover.

Ikerd (1984) reported on the use of invert replacement by the Alabama DOT, where a corrugated metal structural plate pipe was at the bottom of a 41-m (135-ft) fill (Figure 12). Also, Duncan (1984) reported that Montana inserted an asphalt-coated pipe into a deteriorating structural steel plate pipe arch culvert. Meanwhile, in 1985, the FHWA evaluated various repair methods under the Experimental Projects Program to determine the best method to rehabilitate pipes on the Skyline Drive in Virginia (Beucler 1985). They concluded that the inverted-resin impregnate felt tube process was the method that should be used to rehabilitate these 50-year-old pipes. Sukley and St. John (1994) reported on the performance of the polyester fiberfelt, thermosetting resins, and polyurethane pipe rehabilitation process used on a PennDOT project over a 9-year study period. The "pipe in a pipe" performed satisfactorily and saved PennDOT an estimated \$170,000. In addition, the liner improved the flow in the pipe and required little excavation.

In 1997, Okpala and Anderson reported that slipliners were cost-beneficial when compared with excavating and replacing a deteriorating pipe. At one site they indicated that a 52% savings was achieved over the estimated cost of excavating and replacing. In conclusion, they reported that cost savings will be greater as the depth of the pipe increased, traffic delays increased, and other interruptions to the traveling public, such as detours, are factored into the analysis.

TABLE 12
LOUISIANA PIPE SELECTION TABLE (Courtesy of Louisiana DOT)

EDSM NO. II.2.1.1		
Design Service Life and Material Selection for Culverts and Storm Drains (3)		
Application	Materials (Type Joints) (1)	Minimum Design Service Life
1. Storm drains, flumes, and other watertight systems	RCP(A)(T3), RCB, PRCB(T3), RPVCCP(T3), RPECP(T3)	70 years
2. Cross drains for: freeways F-1, F-2, F-3 urban arterial UA-1, UA-2 rural arterial RA-1, RA-2, RA-3, RA-4 urban collector (4 lanes) RC-3	RCP(A)(T3), RCB, PRCB(T3), RPVCCP(T3), RPECP(T3)	70 years
3. Cross drains for: urban collector (2 lanes) UC-1, UC-2, UC-3 rural collector (2 lanes) RC-1, RC-2, RC-3 urban local UL-1, UL-2 rural local RL-1, RL-2, RL-3	RCP(A)(T2), RCB, PRCB(T2), RPVCCP(T2), RPECP(T2), PCCSP(A)(T2), BCCSP(A)(T2), CAP(A)(T2)	50 years
4. Side drains	Same as 3 except Type 1 joints(T1) and Add CPECP(T1), CSP(A)(T1), PVCCP(T1)	30 years
5. Underdrains	Perforated Pipe Underdrains (see Specifications)	(2)
6. Special installations	RPVCCP, RPECP, PCCSP(A), BCCSP(A), CAP(A), CPEC	See Section B

Notes: (1) When design requirements make the use of pipe arch necessary, the specified materials and type joints will be used.
(2) Same as drains with 50-year design life.
(3) Other alternates, when approved, will be added by revising this EDSM.
(4) (A) designates arch option.

Material Type Abbreviations and Definitions:

RCP = reinforced concrete pipe; RCPA = reinforced concrete pipe arch; RCB = reinforced concrete box culvert; PRCB = precast reinforced concrete box culvert; CAP = corrugated aluminum pipe; CAPA = corrugated aluminum pipe arch; CSP = corrugated galvanized steel pipe (no coating); CSPA = corrugated galvanized steel pipe arch (no coating); BCCSP = bituminous coated corrugated steel pipe; BCCSPA = bituminous coated corrugated steel pipe arch; PCCSP = polymer coated corrugated steel pipe; PCCSPA = polymer coated corrugated steel pipe arch; RPVCCP = ribbed polyvinyl chloride culvert pipe; PVCCP = polyvinyl chloride culvert pipe (AASHTO M304); CPECP = corrugated polyethylene culvert pipe (AASHTO M294—Type S); RPECP = ribbed polyethylene culvert pipe [ASTM F894—Ring Stiffness Constant (RSC) of 160]; T1 = Type 1 Joints—To be used for side drains culvert pipe. The combination of gasket material and joint to prevent infiltration. (See specifications for more detailed information.) Type 2 or 3 joints may be used; T2 = Type 2 Joints—The combination of gasket material and joint configuration meets the 5 psi hydrostatic pressure test. (See specifications for more detailed information); and T3 = Type 3 Joints—The combination of gasket material and joint configuration meets the 10 psi hydrostatic pressure test. (See specifications for more detailed information).

Transportation agencies are also either jacking or boring pipes or lining the deteriorated pipe with polyethylene (Tymkowicz 1995), polyvinylchloride, polypropylene, thermosetting glass-reinforced plastic, cement mortar, or smooth or corrugated steel pipe. One critical issue with a liner is the thickness of the liner wall. The liner wall needs to be as thin as possible so as to minimize the reduction of the cross-sectional area and flow capacity of the pipe. The

liners can be forced through the pipe by pushing (pipe jacking) or by being pulled through the pipe (Figures 13 and 14). When only a segment or small portion of a pipe needs to be repaired, a section or two of liner can be installed. A small section of lining is positioned at the deteriorated area and then jacked against the existing pipe (Figure 15). Another method of lining a pipe is with a cement mortar liner, where the liner is formed from cement

TABLE 13
MONTANA SERVICE LIFE GUIDELINES (Courtesy of Montana DOT)

Soil pH	Resistivity	Steel	Type II Aluminized Steel	Aluminum	Concrete
pH > 8.5	R > 1000	Note 1	Note 5	No	Note 3
	800 < R < 1000	Note 1	No	No	Note 3
	500 < R < 800	Note 6	No	No	Note 3
6 < pH < 8.5	R < 500	No	No	No	Note 3
	R > 2200	OK	OK	OK	Note 3
	1000 < R < 2200	Note 1	OK	OK	Note 3
	800 < R < 1000	Note 1	No	OK	Note 3
	500 < R < 800	Note 6	No	No	Note 3
5 < pH < 6	R < 500	No	No	No	Note 3
	R > 1000	Note 1	OK	OK	Note 4
	800 < R < 1000	Note 1	No	OK	Note 4
	500 < R < 800	Note 6	No	No	Note 4
3 < pH < 5	R < 500	No	No	No	Note 4
	All	No	No	No	Note 4
pH < 3	R > 300	No	No	No	Note 4
	R < 300	No	No	No	No

- Notes:
1. Use an approved bituminous or polymeric coating.
 2. Where marble pH is higher than pH by 0.2 or more, steel pipe shall have an approved bituminous or polymeric coating.
 3. Where sulfate content is between 0.25% and 1.0%, use Type 5 cement. Where sulfate content is greater than 1.0%, use Type 5 cement and either an approved bituminous coating or “C Wall” pipe.
 4. Use Type 5 cement and either an approved bituminous coating or “C Wall” pipe.
 5. Use an approved bituminous coating. No gage reduction allowed for the difference between Type II aluminized steel and galvanized steel.
 6. Use fiber-bonded coating.

TABLE 14
METAL LOSS RATES FOR STEEL BY GEOGRAPHIC LOCATION
(Courtesy of NYSDOT)

Zone I (2 mils/yr)		Zone II (4 mils/yr)	
Region 1	except	Albany, Greene, and Schenectady Co.	
Region 2	except	Montgomery Co.	
Region 3	except	Cortland, Tompkins Co.	
Region 4	—	—	
Region 5	except	Cattaraugus Co.	
—	—	Region 6	
Region 7	—	—	
—	—	Region 8	
—	—	Region 9	
—	—	Region 10	
—	—	Region 11	

TABLE 15
ANTICIPATED SERVICE LIFE (in years) FOR STEEL (with and without additional coating) (Courtesy of NYSDOT)

Gauge	Galvanized (Metallic Coated)		Galvanized w/Paved Invert or Fully Paved		Galvanized w/ Polymer Coating		Galvanized w/Polymer Coating and Paved Invert		Galvanized w/Paved Invert (Structural Steel Plate)	
	§707-02/§707-09		§707-02 ³		§707-02 ⁴		§707-02 ⁵		§707-09 ⁵	
	Zone I	Zone II	Zone I	Zone II	Zone I	Zone II	Zone I	Zone II	Zone I	Zone II
18	26	13	51	38	46	33	61	48	Gauge not manufactured	
16	32	16	57	41	52	36	67	51		
14	40	20	65	45	60	40	75	55		
12	54	27	79	52	74	47	89	62	89	62
10	69	34	94	59					104	69
8	84	42	109	67					119	77
7	94	47							129	82
5	109	54	Coating option not specified for these gauges		Gauge not manufactured with this coating				144	89
3	124	62							159	97
1	140	70							175	105

- Notes:
1. For culverts whose diameter, or equivalent diameter, is 3,000 mm or greater:
 - a. in Zone I—specify a paved invert for 12-gauge culverts, or specify a 10-gauge culvert.
 - b. in Zone II—specify a paved invert for all culverts regardless of gauge.
 2. Use caution in designing culverts on grades steeper than ±6% carrying potentially abrasive bed loads. Do not rely on polymer coating alone to increase the service life in abrasive conditions. Use fully paved pipe or paved invert. In very severe conditions, consider use of concrete or polyethylene. Aluminum is not recommended due to the potentially abrasive bed load.
 3. Additional coating adds 25 years to the anticipated service life of galvanized steel pipe.
 4. Additional coating adds 20 years to the anticipated service life of galvanized steel pipe.
 5. Additional coating adds 35 years to the anticipated service life of galvanized steel pipe.

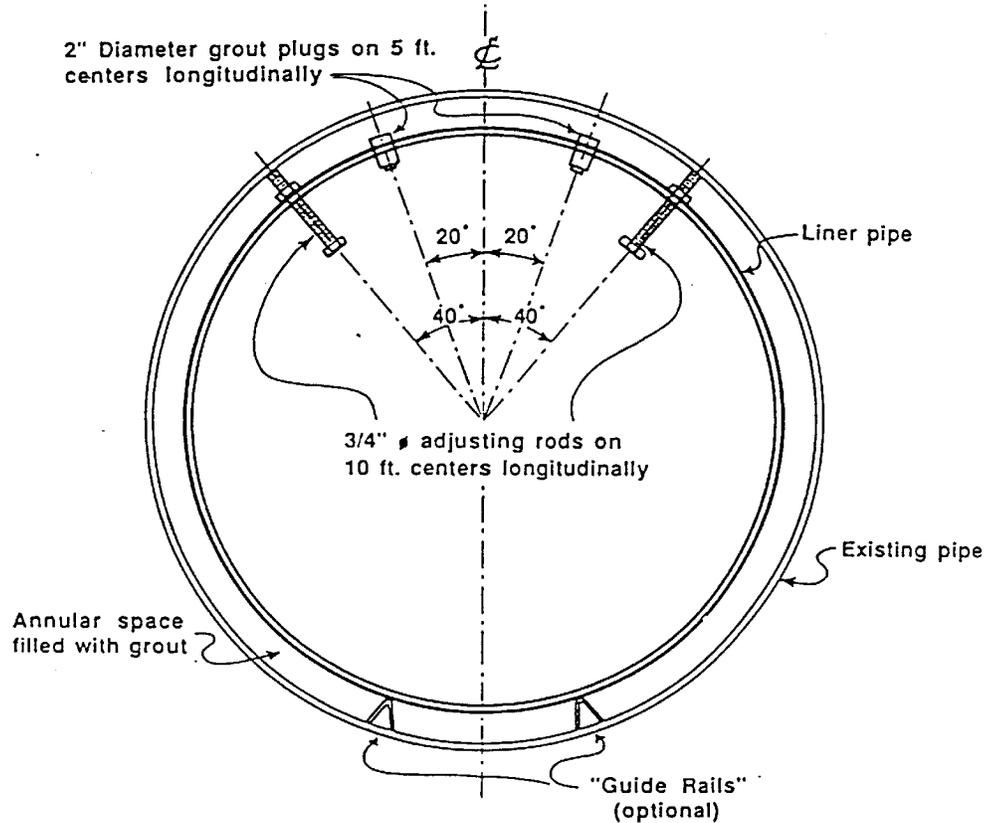
TABLE 16
ADDITIONAL COATING OPTIONS (Courtesy of NYSDOT)

Additional Coating	Corrugated Steel (§ 707-02)	Corrugated Structural Steel Plate (§ 707-09)
Paved Invert (Bituminous)	Type I and II only	Not available
Fully Paved (Bituminous)	Type I and II only	Not available
Polymer	Type I and II only	Not available
Polymer and Paved Invert (Bituminous)	Type I and II only	Not available
Paved Invert (Portland Cement Concrete)	Not available	Available

TABLE 17
METHODS OF STRUCTURAL STABILIZATION USED BY AGENCIES

Method	Yes	No	No Response
Lining	37	8	4
Shotcrete	9	25	5
Cut and Cover (excavate and backfill)	19	17	4
Invert Paving	22	17	3

Note: The number of respondents answering this question varied because several of the respondents left some of the questions unanswered. For example, 49 agencies replied to the question concerning lining, whereas only 39 replied to the question about using shotcrete.



RELINING EXISTING PIPE

FIGURE 11 Details of lining an existing pipe (Lane Enterprises, Inc. 1999).

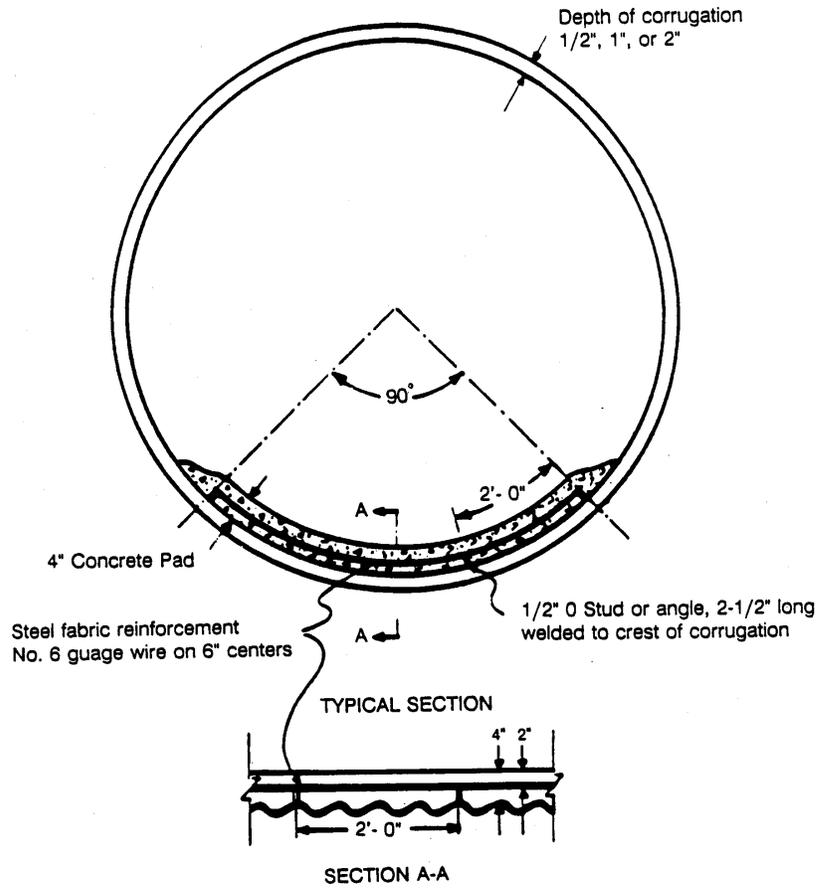


FIGURE 12 Invert paving of steel pipe (Ballinger and Drake 1995).

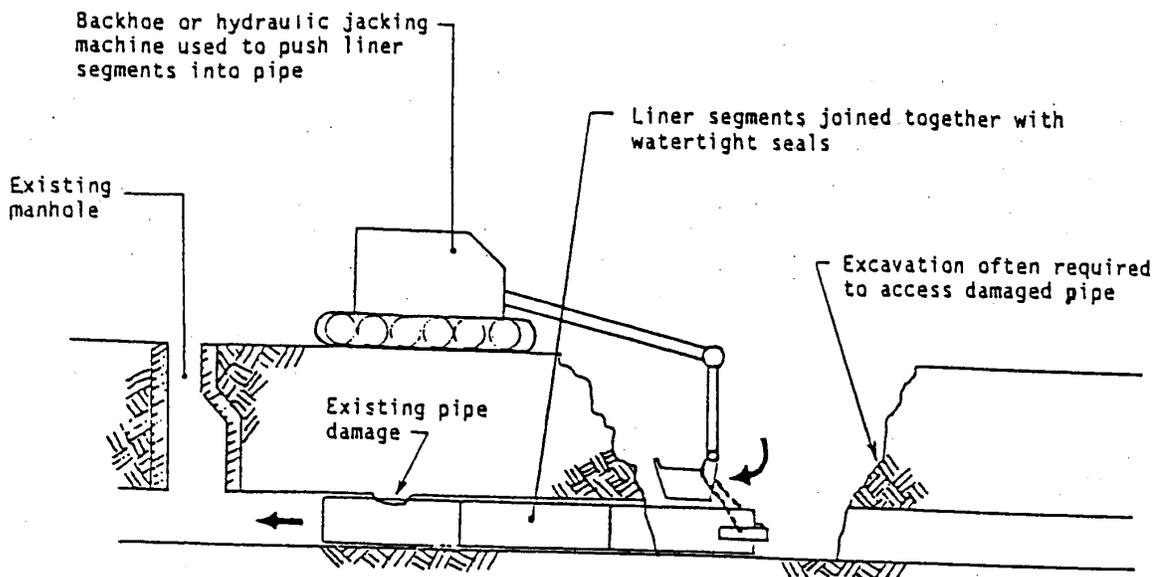


FIGURE 13 Conventional slip lining (Beucler 1985).

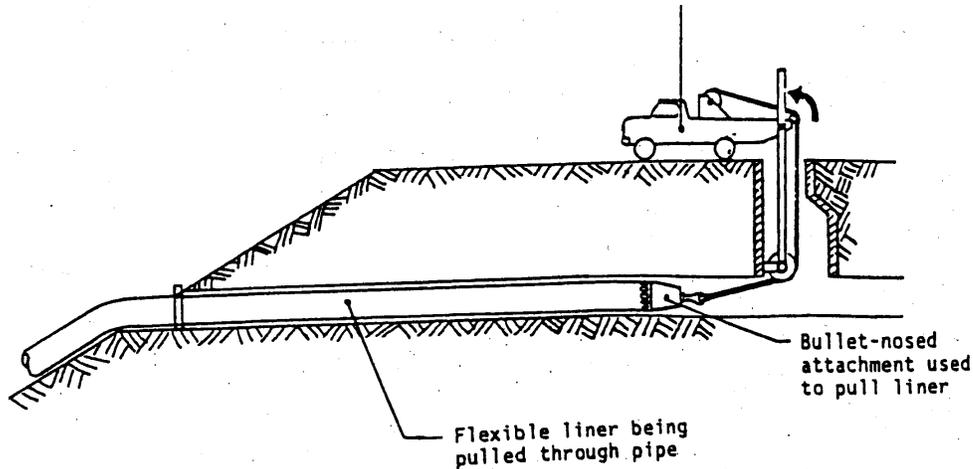


FIGURE 14 Pull-through slip lining (Beucler 1985).

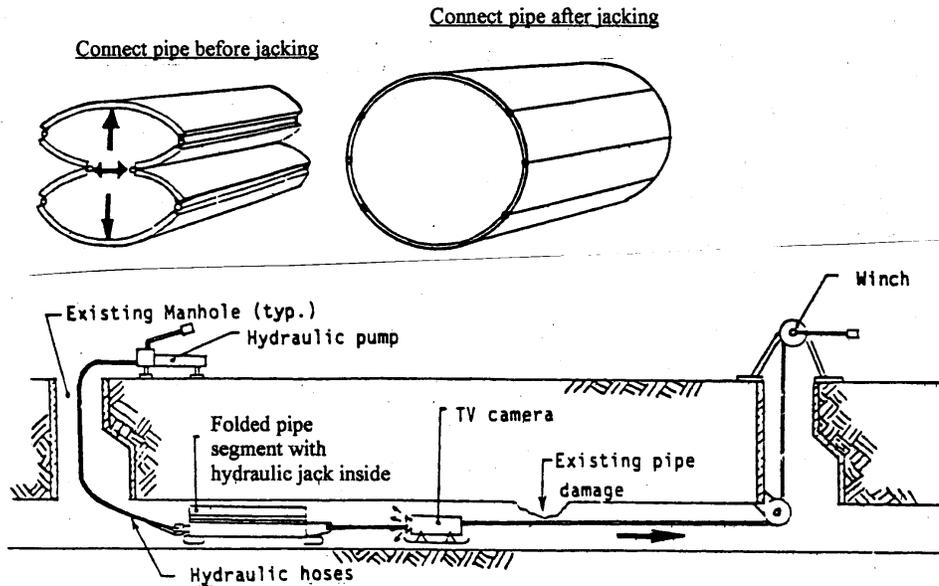


FIGURE 15 Lining small deteriorated areas (Beucler 1985).

centrifugally thrown from a rotating machine as it passes through the original pipe. The cement adheres and compacts against the existing pipe as a result of the centrifugal force. The thickness of the cement depends on the speed of the machine as it travels through the pipe (Figure 16). In 1994, Najafi published a useful study comparing the many proprietary systems of pipe lining. He reported on the principles of material selection, installation methods, the performance of each system, and how the systems vary.

Several states indicated that they initially investigated repairing a pipe or, in some cases, lining the invert with reinforced concrete. However, if the culvert has deteriorated to

a point where it cannot support the loads, lining the entire surface of the pipe or sliplining with a new pipe is considered the best form of rehabilitation. Replacement of the pipe is the final option available when the pipe is experiencing advanced deterioration, reduced hydraulic capacity, or increased elevation of the invert (Alexander et al. 1994). Table 11 is a simplified table used by the Arkansas State Highway Commission to select the type of pipe for different classes of roads. The Utah DOT uses an approach that distinguishes between metal and concrete pipes and requires pH, resistivity, and soluble salts data (Appendix F, Figures F6 and F7). The charts will yield the predicted service life for each class of pipe. Other state DOTs, such

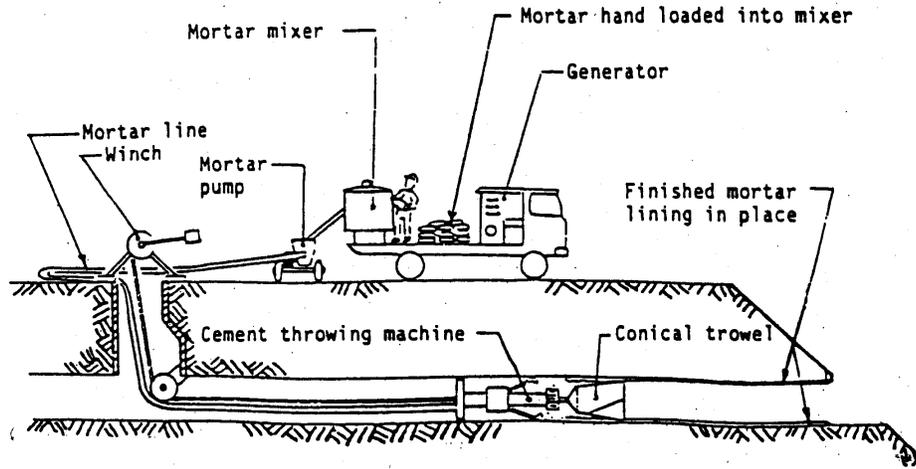


FIGURE 16 Cement mortar lining (Beucler 1985).

as Caltrans, use charts that indicate the minimum thickness of different metals to get a 50-year service life from the pipe (Appendix F, Figures F1 and F2). Caltrans can also increase the service life by coating the pipe with non-metallic material (Appendix F, Figure F3).

All agencies reported that when pipe replacement is done by making an open cut, they either had to design a detour, construct a temporary bypass, or stage the construction.

Staging the construction allowed for half of the roadway to be open to traffic at all times. Also, stage construction requires that some form of traffic control be in place, such as flag persons or a traffic light. The method of traffic control during pipe replacement is usually handled on a case-by-case basis, depending on the conditions at each pipe location. Any form of traffic control at pipe replacement locations is expensive; therefore, trenchless methods are preferred.

PIPE MANAGEMENT ADMINISTRATION

MANAGEMENT SYSTEMS

Eleven agencies (19% of respondents) indicated that they had a management system that uses the pipe assessment data (Table 4). MDOT reported having a pipe management system that is part of a larger system, TINIS, the Transportation Integrated Network Information System (*Inventories of Managed Assets* . . . 1999). The highway records system has been in use since the early 1970s and contains the inventory of managed assets that is accessed by using a node-link framework. A manual is provided to all personnel using TINIS that describes the methods by which data are collected and maintained. The collected data are stored in a centralized database, Inventory of Managed Assets, which supports TINIS. MDOT feels it is using its resources effectively by knowing the quantity, location, and condition of its features. In addition, TINIS is made available to those personnel responsible for maintaining the features and planning the maintenance work effort. TINIS provides quick, desktop access to the data, and allows the staff to plan their work, report their accomplishments, and make their resource needs known to management. Appendix C contains two drainage items from the Inventory of Managed Assets manual. The complete section for cross culverts and struts, excluding photographs, is shown in Appendix C. These sections illustrate the detail required to develop a pipe management system that is a subset of a larger transportation system.

Caltrans, Utah DOT, and other transportation agencies use resistivity and pH charts to achieve the service life expected or to determine the service life for a particular environmental situation (Appendix F, Figures F1–F7). Caltrans also has a computer program that can be used to estimate the service life for various corrosive conditions. Generally, when service life is an issue, the deteriorated pipe is being replaced or lined by a new pipe.

The review of literature revealed that little work has been done on developing a pipe or culvert management system. In 1989, McNichol of the University of Kansas developed a computer-based culvert management system. In 1991, Kurt and McNichol evaluated the system for the culvert systems of a local Kansas agency. The proposed computer system compared well with the existing replacement strategies. This system used four priority-ranking formulas that control user and agency cost. Those formulas considered the following factors: hydraulic capacity, load capacity, width deficiency, and maintenance costs. A

complete management system would involve an evaluation of the life-cycle costs, deterioration models for each culvert type, and the effects of different maintenance strategies. Also, in *NCHRP Synthesis 254*, the Arizona and Mississippi DOTs were reported as having “a particularly well-defined way of addressing and presenting the menu of choices that are associated with the desired service life” (Gabriel and Moran 1998). Included in the parameters that have been evaluated by the states are the performances of different pipe materials; that is, steel, aluminum, concrete, and polyethylene, under various environmental conditions and environments of service. Different states adopt their own strategy to meet their needs from experiences with the various products.

To provide guidance to local governments and others, the FHWA, through the LTAP, developed a CMS (Thompson 2000). However, none of the responding agencies, including the local agencies, indicated that they are using this product in their work. A manual was published containing background information and the details of the system. A field manual was also created to aid the pipe inspector during the evaluation of a pipe. A training course was developed to familiarize all personnel involved with the pipe program and specifically the CMS. The final product of the CMS is a computer software program designed to expedite the implementation process. The computer program contains five modules with flow diagrams and data forms. The five modules are: inventory of the culverts, condition and ratings, work needs (repair or rehabilitation), work funding and prioritization, and scheduling (time of the year and whether in-house or contract). A flow diagram with accompanying data forms to enable users to successfully complete each module is also provided. NYSDOT takes the individual culvert rating data and summarizes them into an annual culvert inspection report. Table 8 is a sample annual report generated from the rating reports (Figure 8). NYSDOT stores its culvert data in a centralized database, but does not incorporate the data into a larger management system, such as MDOT’s TINIS. Potter and Schindler suggested that life-cycle cost analysis (LCCA) be used to determine the relative economic rating of design alternatives of U.S. Army drainage structures (Potter 1988; Potter and Schindler 1988). The use of LCCA can improve the pipe and material selection process and can be done for each site. Once the service life of a drainage material is selected, the procedures for LCCA are established and published in U.S. Army technical manuals. The LCCA considers all costs, direct and indirect, that are

likely to occur over a selected period of the desired service life. Indirect costs, such as the cost of a detour to the user of the transportation system and other costs associated with the disruption of services, need to be included. The alternatives can then be selected from the generated life-cycle order ranking (Potter 1988).

The American Concrete Pipe Association's Least Cost (Life Cycle) Analysis microcomputer program compares different pipe materials based on design components and project requirements (Kurdziel 1988). The program considers the material service life, project design life, economic factors, and other factors specific to the project; for example, traffic costs. The National Corrugated Steel Pipe Association has also developed least-cost analysis software similar to that of the American Concrete Pipe Association.

RECORD KEEPING

A key element for the generation of deterioration curves for individual pipes is derived from records collected over the years that the inspections were performed. The data should be transferred to a centralized database once the inspection forms return to the office. After keying the data in or downloading the files, the hard copy reports should be kept for future reference. If there should be some discrepancies in the data, the hard copies can be secured and validation of the data conducted.

Inspection Reports

Twenty-seven respondents (60% of those answering this question) indicated that they kept the data generated from their inspection programs (Table 4), with 18 agencies having an inspection program, but not keeping their data.

Several one-page inspection reports are being used by transportation agencies, including PennDOT, Caltrans, NCDOT, Mn/DOT, and the Harford County Department of Public Works. An ideal inspection report would have guidelines or rating scales as references on the one-page report. At a minimum, the guidelines or rating scales should be attached to the report. PennDOT has a one-page report with the references at the bottom (Figure 2). A thorough understanding of the rating scale or guidelines is essential to collect accurate and consistent data. PennDOT provides training in the use of their report and the understanding of the guidelines and rating scales. Photographs are also an excellent aid for evaluators to use as a reference during field inspections.

Maintenance Reports

Eighteen of the 59 respondents (31%) to the questionnaire indicated that they had a preventative maintenance program and that they kept their data (Table 4). A preventative

maintenance program is a preferred process because inspections can be planned on a regular schedule. However, most agencies responding to the survey, as well as the results from the literature search, indicated that such programs are not in place. As a result, most transportation agencies do not schedule pipe maintenance work, but wait until a problem occurs or is detected through occasional, random inspections. If a preventative maintenance program is established, regularly scheduled inspections can be generated from the existing database. Also, the program will allow the manager to change the frequency of inspections based on the data accumulated over time. If the pipe is deteriorating at a much faster rate due to a number of factors, the frequency of the inspections can be increased to avoid any failures; that is, from a 4-year cycle to a 2-year cycle. Conversely, the frequency of inspection can be decreased if conditions are milder than anticipated.

SPECIFICATIONS

Thirty-one respondents (54%) indicated that they used material specifications from the construction unit during the rehabilitation of pipes (Table 4). Most state agencies indicated that they use their own standard specifications for road and bridge construction, specifications of AASHTO, or specifications of the American Society for Testing and Materials (ASTM; A849 and A979/A979M). Local agencies indicated that in most cases they use their state DOT's specifications. With some pipe contracts, special provisions for pipe liner installations and other specialized treatments are used in addition to the state's standard construction specifications. Wyoming's Special Provision for Pipe Liner Installation (Appendix D) is an example of such a special provision. This Special Provision covers the description of the work, materials, construction, method of measurement, and basis of payment. NYSDOT is working to standardize their specifications to eliminate redundancies and inconsistencies between special specifications for different activities. A draft specification and design guidelines for rehabilitation of culvert and storm drains for future NYSDOT contracts are provided in Appendix E. The NCDOT and Louisiana DOT have similar specifications for drains and pipes made from various materials, but these are not covered in this synthesis.

Although specifications and special provisions are being used, enhancement of specifications for lining and other rehabilitation methods require further refinement. The lining specifications need to be definitive as to the amount of bend of the insert that will be tolerated before the insert is out of specification. In addition, the pressure required on the grout to ensure that it is properly placed between the two pipes and that voids in the existing pipe and behind the existing pipe are satisfactorily filled must be determined.

Specifications for rehabilitation work are different from the specifications used to place a pipe in an open cut. Open cut specifications deal with compaction of the backfill and bedding material, but rehabilitation specifications do not. In rehabilitation work a clean existing pipe is essential. All loose material must be removed by either water or sand blasting to ensure proper bonding of the existing culvert with the new lining material. In some pipes there are utility services. Specifications need to cover the responsibility of these utilities and the re-establishing of services to their original condition. Another concern for some of the processes used in pipe rehabilitation work involves the curing of the materials. The specifications need to state the temperature levels expected in curing and cooling the products.

Also, the contractor will need to provide points on the incoming and outgoing supply lines to monitor these temperatures for compliance. These examples of specifications needed for rehabilitation work are not all-inclusive, but are examples of the unique specifications needed for rehabilitation work. In addition, these specifications will differ depending on the type of rehabilitation work being done; that is, lining with a pipe, cement mortar lining, or lining a small deteriorated section of the existing pipe. ASTM has two specifications that could be used as guides in the development of lining specifications, specifications for lining a pipe in the manufacturer's plant, ASTM A849-00 (ASTM 2001) and ASTM A979/979M-97, the specification for lining a pipe in the field (ASTM 2001).

CONCLUSIONS

From the results of the literature search and the survey of transportation agencies, it was discovered that there is no consistent and comprehensive methodology among transportation agencies to inventory, inspect, and evaluate pipes and culverts in the field. Several agencies have portions of a comprehensive system, but not one has a complete system in place.

Transportation agencies that have implemented a management system, for example, pavement, bridge, or sign, usually gradually expand and enhance their system, because they realize its benefits and how it allows them to better manage their assets. This progression would inevitably occur with a pipe management system once a transportation agency implemented a pipe system.

The Maine Department of Transportation (MDOT) has the most comprehensive system of all agencies responding to the survey. Once pipe data are collected, the data are entered in a centralized database that will eventually load into a larger management system, the Transportation Integrated Network Information System (TINIS). The data in TINIS can be used for planning, projecting, forecasting, funding, and scheduling inspection times. If similar methodologies were developed by other agencies, the resulting database could provide much useful information for developing improved service-life predictions and generating pipe deterioration curves. Of those responding to the survey, MDOT's DOT's system was the best example of how a pipe assessment guideline can be incorporated into a master management system.

NYSDOT, Caltrans, PennDOT, NCDOT, Mn/DOT, ConnDOT, Maryland State Highway Administration (MDSHA), and the Harford County (Maryland) Department of Public Works have pipe management systems established that could be helpful to an agency just getting started in this area. Summary sheets of the condition rating forms for the individual pipes are generated by most of these agencies. In addition, each transportation agency has detailed training guidelines for their different ratings and most of the agencies include photographs for better understanding. A pipe evaluator in these systems is trained on the system prior to the fieldwork, so that accurate and consistent data are collected by different evaluators even in different regions of the transportation agency.

Most of the agencies responding to the survey do not have a regular pipe inspection schedule because they do

not have a systematic, preventative maintenance program. Some transportation agencies inspect pipes every 4 years, whereas others inspect pipes when time and funding allow. The FHWA has suggested that inspections be scheduled every 2 years for larger pipes and culverts. The MDSHA has a pipe management program where each pipe is inspected every 4 years unless the pipe conditions deteriorate, in which case the pipe is placed on a 2-year inspection cycle.

In addition to the repair or replacement of a deteriorated pipe found during infrequent inspections, repairs or rehabilitation are also scheduled when a defect, such as roadway settlement, occurs unexpectedly. Such repair or rehabilitation jobs are generally expensive and create other maintenance scheduling problems.

The type of defect dictates the type of repair required. If a pipe has deteriorated to a point where more than repair work is required (rehabilitation), most agencies indicated a preference to lining the existing pipe rather than replacing it.

Only one responding agency, the Alameda County Public Works Agency, indicated that they used a video camera to inspect pipes. The remaining respondents did not specify the use of a video camera, but indicated that they performed most of their evaluations from the ends of the pipe (i.e., visually). The condition of the pipe's interior and the appurtenances is determined by an inspector who looks through the pipe with a light.

There have been a number of studies on the load capacity of pipes and the compaction of the soil around the pipes. In addition, a number of studies on the abrasion, corrosion, and durability of various types of pipes, metal pipes in particular, have been conducted over the last 75 years. States have documented relationships between the durability and service life of various types of pipes from these studies and use charts and graphs with these relationships to determine what type of pipe to use to replace an existing pipe.

With these study findings in mind, the following are some opportunities for future research.

- *Transportation agencies would benefit from guidelines for a preventative maintenance program to*

inventory and inspect culverts on a regular schedule. Such a program might include the pipe inventory, guidelines for evaluation of the pipes, photographs related to the guidelines, frequency of inspection, and training for the inspectors. The guidelines might indicate a means of inspecting the interior of small-diameter pipes. Another issue is centralizing culvert data at the appropriate management level, so that analyses can be performed to determine when to schedule pipe inspections, schedule corrective maintenance action, and generate history and deterioration curves for various conditions.

- *Specifications for pipe lining need to be developed.* The Wyoming DOT's Special Provision for Pipe Liner Installation and NYSDOT specifications shown in Appendixes D and E, respectively, are examples that could be referred to in setting a strategy for developing specifications, as well as ASTM's A849-00 Specification for post-applied linings in a manufacturer's plant and A979/A979M-97 Specification for field installed linings.
- *A follow-up study could be undertaken to develop a comprehensive pipe management system that all transportation agencies could use.* As this synthesis shows, there is currently little attention paid to pipe management systems; that is, being proactive by managing the pipe infrastructure. When pipes fail for whatever reason agencies react and take corrective action. If a comprehensive pipe management system

was in use, the agency would be managing the system (proactive), rather than being at the mercy of the system (reactive). A proactive system would include guidelines and photographs for inspection, frequency of inspections, standard data forms, guidelines for determining the corrective action needed (repair, rehabilitation, or replacement), record-keeping procedures, analytical methods for determining pipe condition or deterioration rate, and the economic analysis of the action to be taken. To implement this system and ensure that no one agency would be financially burdened, a number of agencies could pool their funds and share the cost of this development. One state could be designated to handle the administrative and day-to-day operations of the project and coordinate the project activities with a consultant. An estimate of the cost of the project would need to be determined, so that each of the agencies could share equally in the cost. At the conclusion of the project each agency would have the latest techniques and a system ready for implementation as described in the final report.

- *Transportation agencies could benefit from developing methods to use during inspection to estimate the remaining service life of a pipe with various defects or levels of deterioration.* An inspector could use the methods to estimate the service life and provide the manager with the data to better schedule maintenance to the pipe.

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GLOSSARY

Most of the definitions used in this synthesis were from Ballinger and Drake (1995). A set of definitions was needed so that all users of this synthesis could understand the specifics used in this work, even though these definitions may be different from the ones used in their agency. Also, other sources and different state DOTs may not use the same definitions because they may prefer to specify a characteristic, such as a different length or opening area for a bridge, culvert, or pipe. The following list defines most of the terms pertinent to this synthesis and is not exhaustive.

Bridge—Structure more than 20 feet in span parallel with the roadway.

Cement mortar lining—Cement mortar grout centrifugally applied to the interior of existing culverts. Grout is applied after cleaning the pipe to protect the pipe and maintain capacity.

Culvert—Structure usually designed hydraulically to take advantage of submergence to increase hydraulic capacity; structure used to convey surface runoff through an embankment; structure, as distinguished from bridges, that is usually covered with an embankment and is composed of structural material around the entire perimeter, although some are supported on spread footings with the streambed serving as the bottom of the culvert; and a structure that is 20 feet or less in centerline length between extreme ends of openings for multiple barrels (see *Bridge*). (Note: In this report when pipes are mentioned culverts are included.)

Durability—Ability to perform its function and withstand its working environment over time or service life.

Inversion lining—Process of inverting pliable tubing into existing pipe with hydrostatic or air pressure to reline existing pipe. The liner is forced against the existing pipe and bonded with thermosetting resins to provide structural strength and improve smoothness.

Invert—Flowline of the culvert (inside bottom) of the transverse cross section of a pipe.

Link pipe lining—Method of pulling a short, folded pipeline segment to the damaged point in an existing pipe and unfolding or spreading the segment into place by jacking.

Patching—Corrective action taken on a specific area of a pipe surface to keep the pipe in a uniformly good and safe condition. Spalling, abrasion, impact, or some other type of loading could cause the defect.

Pipe—Tube or conduit used to convey a fluid. Sometimes called a culvert, storm drain, or storm sewer. A pipe can be made from a number of materials, including steel, concrete, iron, aluminum, polyethylene, high-density polyethylene, or polyvinylchloride.

Preventative maintenance—Maintenance performed to arrest light deterioration that has occurred and to prevent progressive deterioration. Preventative maintenance is cyclic in nature and can be scheduled. Typical activities include joint sealing, concrete patching, invert paving, and mortar repair.

Rehabilitation—Corrective action that takes advantage of the remaining unusable structure in a culvert to build a reconditioned culvert. The action taken will upgrade the pipe to almost its original condition. Rehabilitation is most appropriate for culverts that have deteriorated beyond the point of effective preventative maintenance, but that have not deteriorated to the point where all structural integrity has been lost.

Repair—Corrective action to keep a culvert in a uniformly good and safe condition by correcting specific defects.

Routine maintenance—Maintenance performed on a pipe to keep it in a uniformly good and safe condition by repairing specific defects as they occur. Routine maintenance is often reactive to a situation rather than being a scheduled activity. Typical activities include debris or sediment removal to restore the pipe cross-sectional area.

Shotcrete lining—Application of pneumatically applied cement plaster or concrete to an in-place structure to increase structural strength and improve the surface smoothness.

Sliplining—The process of placing a smaller diameter pipe in a larger diameter existing pipe to improve the culvert structure and repair leaks. The annular space between the pipes is usually filled with grout applied under pressure.

Storm drain—Structure used to convey runoff from a storm event. Sometimes called a pipe or culvert.

Storm sewer—Structure used to convey storm runoff where storm sewers and storm drains are connected. Sometimes called a pipe or culvert.

Structural plate pipe or arch—Plates of corrugated structural steel used to fabricate large culvert structures such as arches or boxes.

APPENDIX A

Survey Questionnaire

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM Project 20-5, Topic 31-03

ASSESSMENT AND REHABILITATION OF EXISTING CULVERTS

QUESTIONNAIRE

Respondent's Agency _____

Respondent _____

Title _____

Address _____

Phone Number _____ Fax Number _____

E-mail Address _____

PLEASE RETURN QUESTIONNAIRE AND SUPPORTING DOCUMENTS BY **May 10, 2000**

TO:

David Wyant
Wilbur Smith Associates
4686 Garth Road
Crozet, Virginia 22932
(804) 823-1360 (804) 823-5102 (Fax)

For questions it would be best to contact David Wyant by e-mail: dwyant@wilbursmith.com

Note: Help from you or someone in your agency familiar with culvert repair and rehabilitation is greatly appreciated. Thanks in advance for your efforts.

Objective of Project—NCHRP plans to publish a synthesis report on transportation agency state-of-the-practice for assessing pipe condition and selecting the appropriate repair or rehabilitation methods for these pipes. Through this questionnaire and a literature search, it is anticipated that methods of assessment, repair, and rehabilitation for plastic, concrete, and metal pipes will be determined. The synthesis will also report the type of inspection and maintenance records that transportation agencies keep on pipe condition. Hopefully, how the methods of assessment, repair, or rehabilitation for pipes are incorporated into a management system can also be reported in this study. Cast-in-place and bridge structures will not be considered, while system appurtenances, such as drainage inlets, manholes, junction boxes, headwalls, endwalls, and wingwalls will be.

I. Record Keeping

- A. Do you have a preventative maintenance program? Yes _____ No _____
- B. Are maintenance records kept on pipes? Yes _____ No _____
- C. What is the frequency of updating the maintenance records? _____ mos.
- D. Do you have an inspection program? Yes _____ No _____ (If no, then go to Section II.)
- E. Are inspection records kept on pipes? Yes _____ No _____
- F. What is the frequency of updating the inspection records? _____ mos.
- G. How are the inspection reports used? _____

- H. _____

(Note: If you have maintenance records or inspection reports, please send a **copy of the records or reports.**)

II. Guidelines for the Assessment of Pipe Conditions

- A. Do you have a standard set of guidelines used to assess pipe condition?
 Yes _____ No _____

(Note: If yes, please send a **copy of your guidelines** with the questionnaire response. If no, then go to Section III.)

- B. Do the guidelines cover the following types of pipe and the size (diameter) of each pipe type?
 (Note: Maximum size should be the largest size pipe covered by these guidelines before using the NBIS inspection guidelines.)

1. Plastic Yes _____ No _____
 Minimum Size _____ in. Maximum Size _____ in.
2. Concrete Yes _____ No _____
 Minimum Size _____ in. Maximum Size _____ in.
3. Metal Yes _____ No _____
 Minimum Size _____ in. Maximum Size _____ in.

- C. Do the guidelines include the assessment of the following?

1. Drainage Inlets Yes _____ No _____
2. Manholes Yes _____ No _____
3. Junction Boxes Yes _____ No _____
4. Headwalls Yes _____ No _____
5. Endwalls Yes _____ No _____
6. Wingwalls Yes _____ No _____

- D. Does the assessment consider the following factors?

1. Hydraulic Capacity Yes _____ No _____
2. Soil Conditions Yes _____ No _____
3. Joint Failures Yes _____ No _____
4. Corrosion Yes _____ No _____
5. Wall Thickness Yes _____ No _____
6. Deflection Yes _____ No _____
7. Cracking Yes _____ No _____
8. Other Factors _____

- E. Do the guidelines have a section where the assessor suggests the pipe be repaired or rehabilitated?
 Yes _____ No _____

- F. If yes, are there aids for the assessor to use in making this decision between repair and rehabilitation?
 Yes _____ No _____

(Note: If yes, please send a **copy of the aids** with the questionnaire response.)

III. Guidelines for the Selection of Repair and Rehabilitation Methods

- A. Do you have a standard set of guidelines used to select the most appropriate repair method? Plastic Yes _____ No _____
Concrete Yes _____ No _____
Metal Yes _____ No _____
- B. Do you have a standard set of guidelines used to select the most appropriate rehabilitation method? Plastic Yes _____ No _____
Concrete Yes _____ No _____
Metal Yes _____ No _____

(Note: If yes to questions A or B or both, please send a **copy of the guidelines.**)

- C. What permanent solutions do you use for structural stabilization?
(Copies of documents explaining the solutions are appreciated.)

- 1. Relining Yes _____ No _____
- 2. Shotcreting Yes _____ No _____
- 3. Cut and Cover Yes _____ No _____
- 4. Invert Paving Yes _____ No _____
- 5. Others _____

- D. What temporary solutions do you use for structural stabilization? _____

- E. What factors are considered when selecting a replacement pipe? _____

- F. Do you have published or unpublished documents of case histories of reconditioned pipes?
Yes _____ No _____

(Note: If yes, please forward **copies of the documents** with the questionnaire response.)

- G. What methods are used to maintain traffic during pipe work?

IV. Rehabilitation Material Specifications

- A. Do you have material specifications for rehabilitation or replacement pipes?
Yes _____ No _____
- B. Do you have material specifications for repairs made to pipes?
Yes _____ No _____

(Note: If yes to either question, please provide a **copy of the specifications** with the questionnaire response.)

V. Methods of Predicting Service Life of Culverts and Pipes

- A. Do you have a method or methods for predicting the service life of a pipe or culvert?
- | | | | | |
|----------|-----|-------|----|-------|
| Plastic | Yes | _____ | No | _____ |
| Concrete | Yes | _____ | No | _____ |
| Metal | Yes | _____ | No | _____ |
| Other | Yes | _____ | No | _____ |

(**Note:** If yes, please provide a **copy of the method** with the questionnaire response.)

VI. Management Systems

- A. Do you have a management system that uses the data from the pipe assessment?
Yes _____ No _____
- B. Do the guidelines for assessment of pipe conditions result in a priority list, which is subject to monetary constraints? Yes _____ No _____
- C. What type system are you using?
1. Risk analysis _____
 2. Life-cycle-cost optimization _____
 3. Prioritization _____
 4. Planning _____
 5. Other _____

(**Note:** If you have a management system, please forward a **copy of the system** with the questionnaire response.)

Please provide **copies of all of your supporting documents and reports** for the questions along with the questionnaire response to the following address by **May 10th**.

David Wyant
Wilbur Smith Associates
4686 Garth Road
Crozet, Virginia 22932

Thank you for your time and contribution to this study!

APPENDIX B

Agencies Responding to Questionnaire

DOTs Returning Questionnaire

Arizona Department of Transportation
206 South 17th Avenue, MD 176A
Phoenix, AZ 85007-3213

Arkansas State Highway & Transportation Department
P.O. Box 2261
Little Rock, AR 72203-2261

California Department of Transportation
P.O. Box 942874
Sacramento, CA 94274-0001

Connecticut Department of Transportation
280 West Street
Rocky Hill, CT 06067-3502

Florida Department of Transportation
605 Suwannee Street
Tallahassee, FL 32399-0450

Georgia Department of Transportation
2 Capital Square
Atlanta, GA 30297

Hawaii Department of Transportation
601 Kamokila Blvd.
Kapolei, HI 96707

Illinois Department of Transportation
126 East Ash Street
Springfield, IL 62704-4792

Indiana Department of Transportation
100 N. Senate Avenue
Indianapolis, IN 47906

Iowa Department of Transportation
800 Lincoln Way
Ames, IA 50010

Kentucky Department of Highways
501 High Street, Room 1005
Frankfort, KY 40622

Louisiana Department of Transportation
P.O. Box 94245
Baton Rouge, LA 70808-9245

Maine Department of Transportation
16 State House Station
Augusta, ME 04333-0016

Maryland State Highway Administration
707 North Calvert Street
Baltimore, MD 21202

Michigan Department of Transportation
P.O. Box 30049
8885 Ricks Road
Lansing, MI 48909-7549

Minnesota Department of Transportation
3485 Hadley Avenue North
Oakdale, MN 55128-3307

Mississippi Department of Transportation
P.O. Box 1850
Jackson, MS 39215-1850

Missouri Department of Transportation
P. O. Box 270
Jefferson City, MO 65109

Montana Department of Transportation
2701 Prospect Avenue
Helena, MT 59620

Nebraska Department of Roads
P.O. Box 94759
Lincoln, NE 68509-4759

New Hampshire Department of Transportation
P.O. Box 483, Hazen Drive
Concord, NH 03302-0483

New Mexico State Highway & Transportation Department
P.O. Box 91750
Albuquerque, NM 87199

New York State Department of Transportation
Building 5, Room 217
1220 Washington Avenue
Albany, NY 12232

North Carolina Department of Transportation
One S. Wilmington Street/P.O. Box 25201
Raleigh, NC 27611-5201

North Dakota Department of Transportation
608 E. Boulevard
Bismarck, ND 58505-0700

Ohio Department of Transportation
1980 West Broad Street
Columbus, OH 43223

Oklahoma Department of Transportation
200 N.E. 21st Street
Oklahoma City, OK 73105-3204

Oregon Department of Transportation
800 Airport Road SE
Salem, OR 97301-4798

Pennsylvania Department of Transportation
555 Walnut Street, 7th Floor
Harrisburg, PA 17101-1900

Rhode Island Department of Transportation
State Office Building/2 Capitol Hill, Room 013
Providence, RI 02903-1190

South Carolina Department of Transportation
P.O. Box 191
Columbia, SC 29202

Tennessee Department of Transportation
James K. Polk Building, Suite 400
505 Deadrick Street
Nashville, TN 37243-0333

Texas Department of Transportation
P.O. Box 5080
Austin, TX 78763-5080

Utah Department of Transportation
Box 148440, 4501 So. 2700 West, 4th Floor
Salt Lake City, UT 84114-8440

Vermont Agency of Transportation
133 State Street
Montpelier, VT 05633-5001

Virginia Department of Transportation
800 E. Leigh Street
Richmond, VA 23219

Washington State Department of Transportation
P.O. Box 47365
Olympia, WA 98504-7365

West Virginia Department of Transportation
1900 Kanawha Blvd., East, Building 5
Charleston, WV 25305-0440

Wisconsin Department of Transportation
4802 Sheboygan Avenue, Room 501
Madison, WI 53707-7965

Wyoming Department of Transportation
P.O. Box 1708, 5300 Bishop Blvd.
Cheyenne, WY 82003-1708

Federal Agencies Returning Questionnaire

National Resource Conservation Service
949 E. 36th Avenue, Suite 400
Anchorage, AK 99508

National Resource Conservation Service
3003 N. Central, Suite 800
Phoenix, AZ 86001

National Resource Conservation Service
700 West Capital Avenue
Little Rock, AR 72201

National Resource Conservation Service
Room E200C, 655 Parfet Street
Lakewood, CO 80215-5517

National Resource Conservation Service
FHB Building, Suite 301
400 Route 8
Maite, GU 96927

National Resource Conservation Service
6013 Lakeside Boulevard
Indianapolis, IN 46278

National Resource Conservation Service
771 Corporate Drive, Suite 110
Lexington, KY 40503-5479

National Resource Conservation Service
3737 Government Street
Alexandria, LA 71302

National Resource Conservation Service
967 Illinois Avenue, Suite 1
Bangor, ME 04401-2700

National Resource Conservation Service
339 Busch's Frontage Road, Suite 301
Annapolis, MD 21401

National Resource Conservation Service
Federal Building, Suite 1321
100 West Capital Street
Jackson, MS 39269

National Resource Conservation Service
Parkade Center, Suite 250
601 Business Loop 70 W
Columbia, MO 65203

National Resource Conservation Service
Federal Building, Room 152
100 Centennial Mall North
Lincoln, NE 68508-3866

Design Branch, U.S. Army Corps of Engineers
215 North 17th Street
Omaha, NE 68102-4978

National Resource Conservation Service
5301 Longley Lane, Building F, Suite 201
Reno, NV 89511

National Resource Conservation Service
441 S. Salina Street, Suite 354
Syracuse, NY 13202-2450

National Resource Conservation Service
200 N. High Street, Room 522
Columbus, OH 43215

National Resource Conservation Service
675 Courthouse, 801 Broadway
Nashville, TN 37203

National Resource Conservation Service
W.R. Porage Building
101 South Main Street
Temple, TX 76501-7682

National Resource Conservation Service
6515 Watts Road, Suite 202
Madison, WI 53719-2726

National Resource Conservation Service
100 E. B Street, Room 3124
Casper, WY 82601-1969

Local Agencies Returning Questionnaire

Los Angeles County Department of Public Works
900 South Fremont Avenue
Alhambra, CA 91803

Alameda County Public Works Agency
951 Turner Court, Room 100
Hayward, CA 94545

San Mateo County Public Works Department
555 County Center, 5th Floor
Redwood City, CA 94063

Routt County Road & Bridge Department
P.O. Box 773598
Steamboat Springs, CO 80477

D.C. Division of Transportation
2000 14th Street, NW, 5th Floor
Washington, DC 20009

Alochua County Public Works
P.O. Box 1188
Gainesville, FL 32602

Collier County Stormwater Management Department
Horseshoe Square, Suite 212
2685 South Horseshoe Drive
Naples, FL 34104

Hillsborough County Public Works Department
601 E. Kennedy Boulevard, 23rd Floor
P.O. Box 1110
Tampa, FL 33601

Fayette County Engineering Department
140 Stonewall Avenue West
Fayetteville, GA 30215

Hamilton County Highway Department
1717 East Pleasant Street
Noblesville, IN 46060

Harford County Department of Public Works
212 S. Bond Street, 3rd Floor
Bel Air, MD 21014-3834

St. Mary's County Department of Public Works
and Transportation
44825 St. Andrews Church Road
P.O. Box 508
California, MD 20619

Saginaw County Road Commission
P.O. Box 1867
Saginaw, MI 48605

Mason County Road Commission
510 East State Street
Scottville, MI 49454

Lake County Minnesota
1513 Highway 2
Two Harbors, MN 55616

APPENDIX C

Examples of Pipe Guidelines and Specifications

Maine DOT's Cross Culverts Guidelines (Maine DOT 1999)

5.1. Cross Culvert - Defined.

A cross culvert is any structure, with less than 60" span width, which crosses beneath the traveled way being inventoried. In the case of multiple culverts, when the total flow area is less than 19 square feet, the structure should be considered a Culvert and be inventoried as a Culvert. Drainage structures, with a flow area is greater than 19 square feet, should be considered a Strut and be inventoried as a Strut. (see page 15)

5.1.1 Cross Culvert - Notable changes from previous collection manuals.

In 1991, when the first inventory was conducted, the definitions of Cross Culverts, Entrance Culverts and Struts were not compatible with each other. A rating of 1 in Struts was not the same as a rating of 1 in Cross Culverts and Entrances. Initially the survey did not count the number of spans as Struts do, but considered each culvert of a multiple set to be a single structure.

It is desirable to have attributes of each structure defined the same way. This would allow the compilation of the three types of structures into one table. In order to accomplish this we have made minor changes from the first Data Collection Manual of 1991.

Cross Culverts should now be treated like a small Strut with many features being the same. Changes will be in *Italicized text and underlined* to help distinguish the changes. A note will show what the language used to be and is included only for your information.

To code the Cross Culvert data entry sheet, begin by filling out the header block in the same manner as for all other data entry forms, entering data in the fields for division, town, route number, direction and sheet.

5.2 CROSS CULVERT - Data Fields

Div:

During data entry on a computer screen, the Division should be automatically entered when the crew number is entered.

Crew :

Enter the crew number for the Maintenance Crew responsible for drainage on the road where this culvert is located.

Town:

Enter the town name from the drop down list. This will enter the proper town GEO Code.

Route Number:

Pick the route from the drop down list or enter the 5 characters of the Route Number as indicated on the strip map. Be sure to use leading zeros in order to maintain 5 digits. Example: 0001X (do not enter in Rte. 1).

Route Mileage @ Culvert:

To code the Mile point on Route put in the TINIS route mileage at the point where the center of the structure crosses the center line of the roadway.

Number of Spans:

A clear span is defined as a passage where water can run which is free of any structural obstructions. Code the number of spans being sure to zero fill any space not needed so that the TWO positions in the field both contain a character. For example, if there are TWO spans enter '02' or select from the drop down list.

NOTE: This was added to make Cross Culverts compatible with Struts. Use the same method to record twin structures as would be used when recording a Strut.

Clear Span width:

Code the total clear span width in inches. The clear span is the horizontal distance between supports in rectangular culverts; and the diameter of round ones. If the culvert exceeds 60" in width or over 19 sq. ft. of drainage area, it will be considered a STRUT and inventoried using the STRUT data entry form.

If the width varies, code the greatest distance found. (This can occur particularly in stone culverts where walls are irregular). Measure the clear span perpendicular to the walls unless they are battered. If they are battered (pitched), measure the horizontal distance between them at the vertical midpoint. All structure widths are to be inside measurements, not including the width of the separating walls.

NOTE: This field used to be labeled "Size:" The original data collection considered each span it's own individual structure. Therefore corrections in the database from the original inventory will need to be done with Cross Culverts that have more than one span.

Length:

Code the length of the structure, to the nearest foot, along the flow line using the following guidelines:

1. Concrete box culverts have a bottom slab below the water line. Measurement shall be to the outside of this slab.
2. Pipe ends beveled to match slope grade shall be measured at the farthest end.

Depth of Cover: (Cover)

Enter the depth of cover material over the culvert at the centerline of the road to the nearest foot. This is measured from the top of the culvert to the finished grade of the roadway.

Condition:

With the effort to keep the drainage structures compatible, we will use the same numeric condition ratings for culverts that was used while inventorying Struts. We will only use three rating for culverts. The change here is the numbers use to rate the structure GOOD, FAIR and POOR. Only use NEW with newly installed culverts.

Enter the number that indicates the condition of the culvert.

- 0 = **Undetermined.** This culvert either could not be found, or the condition was such that it could not be effectively assessed. (e.g.: Ends too buried to survey.)
- 3 = **Poor** This culvert needs replacing, the invert is fully corroded, or the sections are pulling apart; the roadway shows signs of caving in.
- 6 = **Fair** This culvert is operating satisfactorily but some minor maintenance may be required.
- 8 = **Good** This culvert is in good condition and needs no repair.
- 9 = **New** This culvert is in new condition. Use this rating only when updating the database after completion of a new installation or replacement of an existing culvert with a new pipe.

NOTE: Please review the General Notes on Condition found on page 17 of this manual.

Drainage:

Enter the number code which describes the drainage characteristics within approximately 50 feet of this culvert. Answer the question 'How well is this culvert working?' as follows:

- 0 = **Poor** The culvert has substantial blockage, 50% or more; is holding water back; needs major maintenance, i.e. ditching.
- 1 = **Fair** This culvert has minor blockage or scoring; some maintenance required.
- 2 = **Good** This culvert is working satisfactorily; no improvements are needed.

Additional Length Needed:

Enter the number which corresponds to the amount of length which should be added to the culvert to improve the drainage capacity of the culvert and bring it back to a functional level.

- 0 = None
- 1 = Between 1 and 10 feet required.
- 2 = Between 11 and 20 feet required.
- 3 = Between 21 and 30 feet required.
- 4 = More than 30 feet required.

Skew angle:

Estimate the skew of pipe to the nearest five degrees, coding **Cross Culverts** perpendicular to the road as '00' and all others as positive values, no matter which direction the **Cross Culverts** is skewed.

Type:

Type is the combination of the Style and Material fields of the 1991 Cross Culvert data collection Sheet DRD001. Ratings used by this manual uses the common types in the Strut inventory and additional types for the Cross Culvert inventory.

Ratings:

00 = Precast Concrete Pipe 01 = Bitum. Coated Corr. Metal Pipe 02 = Corrugated Metal Pipe
 03 = Concrete Box Culvert 10 = Aluminum Pipe 12 = Composite 13 = Other
 14 = Plastic Pipe 15 = Arched Aluminum Pipe 16 = Arched Steel Pipe
 17 = Plastic Coated Metal Pipe 18 = Slip Lined Pipe 99 = Unknown

NOTE: Type is the combination of the old Style and Material fields

Style:

0 = Circular or round. 1 = Box culvert; square or rectangular. 2 = Arch shaped. 3 = Multiple Pipes. 4 = Other.

Material:

0 = UM = Unknown Metal 1 = GS = Galvanized Steel
 2 = AZ = Aluminized 3 = GA = Galvanized Aluminum
 4 = AL = Aluminum 5 = PL = Plastic
 6 = PC = Portland Cement 7 = CO = Composite
 8 = OT = Other

Notes: Enter any field notes needed for later reference.

After a page is full, initial and date the form in the space provided.

Type:

Type is the combination of the Style and Material fields of the 1991 Cross Culvert data collection Sheet DRD001. Ratings used by this manual uses the common types in the Strut inventory and additional types for the Cross Culvert inventory.

Ratings:

00 = Precast Concrete Pipe 01 = Bitum. Coated Corr. Metal Pipe 02 = Corrugated Metal Pipe
 03 = Concrete Box Culvert 10 = Aluminum Pipe 12 = Composite 13 = Other
 14 = Plastic Pipe 15 = Arched Aluminum Pipe 16 = Arched Steel Pipe
 17 = Plastic Coated Metal Pipe 18 = Slip Lined Pipe 99 = Unknown

NOTE: Type is the combination of the old Style and Material fields

Style:

0 = Circular or round. 1 = Box culvert; square or rectangular. 2 = Arch shaped. 3 = Multiple Pipes. 4 = Other.

Material:

0 = UM = Unknown Metal 1 = GS = Galvanized Steel
 2 = AZ = Aluminized 3 = GA = Galvanized Aluminum
 4 = AL = Aluminum 5 = PL = Plastic
 6 = PC = Portland Cement 7 = CO = Composite
 8 = OT = Other

Notes: Enter any field notes needed for later reference.

After a page is full, initial and date the form in the space provided.

Culvert Guidelines

CODE General Guidelines for all Culverts

- 9 = New Condition.
- 8 = Good Condition
 (1) Age deterioration minor
 (2) No repairs necessary
 (3) No settlement of roadway
 (4) Good Alignment, no deflection in length of culvert
- 6 = Fair Condition
 (1) Age deterioration moderate
 (2) Some settlement of roadway or alignment in structure noted.
 (3) Minor repairs by Maine Department of Transportation could be done
- 3 = Poor Condition
 (1) Age deterioration could be significant
 (2) Repairs to structure not economically feasible
 (3) Future replacement necessary; < 5 years
- 0 = Unknown
 (1) Unable to arrive at an accurate rating.

Note: Guidelines only

Ratings:

00 = Precast Concrete Pipe 01 = Bitum. Coated Corr. Metal Pipe
 02 = Corrugated Metal Pipe 03 = Concrete Box Culvert 10 = Aluminum Pipe
 12 = Composite 13 = Other 14 = Plastic Pipe 15 = Arched Aluminum Pipe
 16 = Arched Steel Pipe 17 = Plastic Coated Metal Pipe 18 = Slip Lined Pipe
 99 = Unknown

Maine DOT's Strut Guidelines (Maine DOT 1999)

4.1 STRUT - Defined

A **STRUT** is any Culvert with a span width greater than five feet and less than ten feet or any combination of pipes such that the total flow area is less than 80 square feet.

To code the **STRUT** data entry sheet begin by filling out the header block in the same manner as for all other data entry forms, entering data in the fields for division, town, route number, direction and sheet.

4.2 STRUT Data Fields

Div:

The division number should be automatically entered when the crew number is entered.

Crew:

Enter the crew number for the Maintenance Crew responsible for drainage on the road this Strut is on.

Town:

Enter the town name from the drop down list . This will enter the proper town GEO Code.

Route Number:

Pick the route from the drop down list or enter the 5 characters of the Route Number as indicated on the strip map. Be sure to use leading zeros in order to maintain 5 digits.
Example: 0001X (do not enter in Rte. 1).

Route Mileage @ Strut:

To code the **Mile point on Route** put in the **TINIS** route mileage at the point where the center of the pipe crosses the center line of the roadway.

Number of Spans:

A clear span is defined as a passage where water can run which is free of any structural obstructions. Code the number of spans being sure to zero fill any space not needed so that the **TWO** positions in the field both contain a character. For example, if there are **TWO** spans enter '02' or select from the drop down list.

Clear Span width:

Code the total clear span width in inches. The clear span is the horizontal distance between supports in rectangular culverts; and the diameter of round ones.

If the width varies, code the greatest distance found. (This can occur particularly in stone culverts where walls are irregular).

Measure the clear span perpendicular to the walls unless they are battered. If they are battered (pitched), measure the horizontal distance between them at the vertical midpoint.

Structural plates are to be measured at the spring line where plates bolt into the unbalanced channels.

All structure widths are to be inside measurements, not including the width of the separating walls.

Length:

Code the length of the structure along the flow line to the nearest foot using the following guidelines:

1. Concrete box culverts have a bottom slab below the water line. Measurement shall be to the outside of this slab.
2. Pipe ends beveled to match slope grade shall be measured at the very end.

Grate:

A culvert which runs beneath the roadway would always be considered buried under grate, while a concrete box culvert may or may not be so considered according to its construction. Indicate whether or not the structure is buried under grate and if so code the depth of grate in feet. Again be sure to completely fill the field.

STRUT Type:

Ratings:

00 = Precast Concrete Pipe 01 = Bitum. Coated Corr. Metal Pipe 02 = Corrugated Metal Pipe
 03 = Concrete Box Culvert 04 = Timber Culvert 05 = Mortared Stone 06 = Dry Stone
 07 = Muilti Plate 08 = Muilti Plate Pipe Arch 09 = Structural Plate Arch
 10 = Aluminum Pipe 11 = Aluminum Multi Plate 12 = Composite 13 = Other
 99 = Unknown

Code the STRUT type according to the table above. Use the drop down list to enter the STRUT type. When culverts are constructed using combinations of materials, code the type which predominates..

Skew angle:

Estimate the skew of pipe to the nearest five degrees, coding STRUTS perpendicular to the road as '00' and all others as positive values, no matter which direction the STRUT is skewed.

Condition:

Code the condition of the STRUT using the chart of values table above according to the following guidelines:

Ratings:

0 = Undermined 1 = Critical 2 = Very Poor 3 = Poor 4 = Marginally Poor
 5 = Marginally Fair 6 = Fair 7 = Marginally Good 8 = Good 9 = New

Pipe/Pipe Arch Condition Rating

This item evaluates the alignment, settlement, distortion, structural condition and scour for pipes and pipe arches.

<u>Code</u>	<u>Description</u>
9	NEW
8	GOOD - no noteworthy deficiencies
7	MARGINALLY GOOD - shape is smooth and symmetrical. Galvanizing is gone (usually below low water elevation) allowing surface rust, but no pitting. Minor scouring near pipe.
6	FAIR - shape has smooth curvature, but non-symmetrical shape. Pitting up to ½ of plate thickness. Local minor scour at pipe end(s); may have some undermining.
5	MARGINALLY FAIR - shape has significant distortion and deflection in one section. Pitting is deeper than ½ plate thickness, but no holes. Scour/erosion has partially to totally exposed a moderate portion of the pipe end(s); roadway width unaffected.
4	MARGINALLY POOR - shape has significant distortion and deflection throughout. Individual holes thru the pipe walls. Scour/erosion has significantly undermined the end(s) or exposed the ends sufficiently to allow distortion to occur; minor roadway shoulder loss.
3	POOR - shape has extreme distortion and deflection. Holes are continuous for partial section, but unlikely to collapse under roadway. Scour/erosion has caused severe loss of fill; travel lane(s) is narrowed or unstable @ edges.
2	VERY POOR - shape has extreme distortion and deflection throughout; roadway probably settled. Extreme section loss could allow collapse/settlement under roadway (unzipped). Scour/erosion has reduced roadway to 1 lane
1	CRITICAL - partial failure.
0	UNKNOWN .

4.2.1 General Notes on Condition

Occasionally, pipes or arches use a log or timber grillage for a foundation. Care should be given to inspecting the inlet or outlet ends of grillage's as undermining of this footing type frequently occurs.

Inspection of the highway surface above the culvert will often give you an indication of problems which may not be visible from below.

4.2.1.1 Precast Concrete Pipe

Inspection of Pipes to include:

Misalignment: Poor compacting procedures can cause misalignment, both vertical and horizontal. Excessive misalignment can cause joints to separate or adjacent pipes to spall at areas next to joints.

Joint defects: Defective joints can either allow water flowing through the pipe to leak into supporting material (infiltration) or conversely allow ground water to leak through joints and into the barrel. Both conditions are to be considered serious as deterioration will accelerate.

Spalling: Spalling of precast concrete pipes frequently occurs along longitudinal or transverse cracks caused by overloading or improper support.

Inlet and Outlet Ends: Either end can show appreciable settlement due to undermining or eroding of embankment material due to water flow.

4.2.1.2 Corrugated Metal Pipes (Both steel and aluminum)

Corrosion: Blistering, or rust nodules occur most often on pipe bottoms. Removal of these nodules reveals pitting of the steel surface. The depth of pitting and the amount of surface area subject to nodules shall be considered when evaluating the condition of the pipe. Obviously pipes suffering perforation shall be rated lower than those with shallow to moderate pitting.

Sagging: The amount of sagging present in pipes and the overall alignment shall be evaluated as to whether a structural problem exists or poor compacting practices have caused the poor alignment. Round pipes or multi-plates whose shape has been severely distorted no longer have the structural load capacity they were designed to carry.

Inlet and Outlet Ends: Damage of inlet and outlet ends due to improper placement, riprap or ice damage shall be considered serious and rated accordingly. Inlet ends broken or crushed inward severely restrict water flow and contribute to both scouring of adjacent banks and the undermining of the structure.

4.2.1.3 Concrete Box Culvert (Box Culverts, Rigid Frames):

Scaling: Scaling of concrete surfaces shall be taken into account when rating condition. Total area of scaling and depth thereof will be considered. Example: Scaling of a depth which reveals reinforcing steel shall be rated lower numerically than "light" scaling over a large surface area.

Spalling: Spalling is defined as voids, usually isolated and deep. Consideration of a numerical condition rating for a structure where spalling is prevalent shall be given to:

1. Location of Spalls: More serious adjacent to a vertical or horizontal joint.
2. Depth of Spalls: Spalls deep enough to reveal reinforcing steel shall be rated lower than shallow spalls of 1" to 1 1/2".

Cracking: The cracking of concrete surfaces should not be rated on its visual appearance alone. Quite frequently concrete that cracks, particularly vertically, is delaminating from inferior

reinforcing steel. “Sounding” of concrete adjacent to cracks will reveal the area of the delamination zone. Large areas would clearly rate lower than small ones. Only upon both visual and physical assessment of concrete cracks can a condition rating be given.

Alignment: Inspect alignment of concrete structure looking for skew or buckling.

4.2.1.4 Timber Culverts

Timber components shall be inspected for weather cracking and checking. Sounding of timber with a hammer will give an indication of interior condition. Exterior rot will be indicated by either crushing of the members or splintering. Interior rot is difficult to detect during a visual or even a sounding inspection. Areas that show horizontal cracking should be considered subject to interior rotting.

4.2.1.5 Stone Culverts (Mortared/Dry Laid)

“Dry” stone struts are those which have no structural bond in the joints. Dry stone struts are particularly susceptible to lateral movement of the walls due to forces from the backfill material. Vertical cracking of stone courses can occur due to long term settlement.

Mortared stone shall have a structural joint material of cement mortar, lead wood packing, or possibly another type. These should be inspected for erosion.

4.2.1.6 Multi-Plate Pipes: (Field Assembled)

In addition to the notes above under ‘Corrugated Metal Pipes’:

Connection seams: The connection seams on multi-plates should be inspected for a cocked or cusped condition. This results from improper erection or fabrication of the plates. This condition appears as plates out of alignment at the connection area. Severe cases can put undue stress on the plates resulting in cracks adjacent to the bolts

4.2.1.7 Structural-Plate Arches: (Field Assembled)

In addition to the notes above under ‘Corrugated Metal Pipes’:

Connection seams: Usually used for wider spans, struts of this type with less than 10’ span will occasionally be found. One area susceptible to deterioration is the connection point where the plates bolt to the footings (unbalanced channel). Complete section loss of the channel or bolts can occur and should be checked closely.

Footings: Attention must be given to the area of the footings where they are cast on ledge. Frequently, undermining of footings occurs due to scouring resulting in areas of the structure being unsupported.

4.2.1 Condition Codes - General Guidelines for all Struts

- 9 = New Condition.
- 7-8 = Good Condition.
 1. Age Deterioration minor.
 2. No repairs necessary.
 3. No settlement of roadway.
 4. Good Alignment.
- 5-6 = Fair Condition.
 1. Age deterioration moderate.
 2. Minor repairs by Maine Department of Transportation could be done.
 3. Some settlement of roadway or alignment in structure noted.
- 3-4 = Poor Condition.
 1. Age deterioration could be significant.
 2. Replacement will be necessary within the next five years.
- 1-2 = Critical Condition.
 1. Failure of structure considered imminent.
 2. Closing of roadway or by-pass may be necessary.
 3. High priority of immediate replacement.
- 0 = Unable to arrive at an accurate rating.
Needs to be done by Bridge Maintenance Manager.

4.2.3 Drainage Condition Guidelines

Flow Banks:

Inspect both upstream and downstream areas prior to giving drainage a numerical rating. Past scouring of bankings both up and downstream needs to be evaluated. Areas to be inspected include vegetation adjacent to the structure and the depth of scour.

Undermining:

Undermining of the inlet and outlet ends of structure, and damage to embankment protective system, if any, should be evaluated in assigning an overall drainage condition.

Strut Guidelines

<u>CODE</u>	General Guidelines for all Struts	
9	=	New Condition.
7-8	=	Good Condition (1) Age deterioration minor (2) No repairs necessary (3) No settlement of roadway (4) Good Alignment, no deflection in length of culvert
5-6	=	Fair Condition (1) Age deterioration moderate (2) Minor repairs by Maine Department of Transportation could be done (3) Some settlement of roadway or alignment in structure noted
3-4	=	Poor Condition (1) Age deterioration could be significant (2) Repairs to structure not economically feasible (3) Future replacement necessary; > 1 year & < 5
1-2	=	Critical Condition (1) Failure of structure considered imminent (2) Closing of roadway or by-pass may be necessary (3) High Priority of immediate replacement
0	=	Unknown (1) Unable to arrive at an accurate rating.

Note: Guidelines only

Strut Data Entry Sheet

Route Mileage @ Strut	<input type="text"/>	Number of Spans	<input type="text"/>	Clear Width of Span	<input type="text"/>	Length of Strut	<input type="text"/>	Buried under cover?	<input type="text"/>	Depth of Cover	<input type="text"/>	Type of Strut	<input type="text"/>	Skew Angle	<input type="text"/>	Strut Condition	<input type="text"/>
Drainage Cond.	<input type="text"/>	Reset Node ID	<input type="text"/>	Notes				<input type="text"/>									
Added Length Needed? <input type="text"/> 0=None 1=1-10 2=11-20 3=21-30 4= 30+																	

Route Mileage @ Strut	<input type="text"/>	Number of Spans	<input type="text"/>	Clear Width of Span	<input type="text"/>	Length of Strut	<input type="text"/>	Buried under cover?	<input type="text"/>	Depth of Cover	<input type="text"/>	Type of Strut	<input type="text"/>	Skew Angle	<input type="text"/>	Strut Condition	<input type="text"/>
Drainage Cond.	<input type="text"/>	Reset Node ID	<input type="text"/>	Notes				<input type="text"/>									
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Drainage Cond.	<input type="text"/>	Reset Node ID	<input type="text"/>	Notes				<input type="text"/>									
Added Length Needed? <input type="text"/> 0=None 1=1-10 2=11-20 3=21-30 4= 30+																	

Route Mileage @ Strut	<input type="text"/>	Number of Spans	<input type="text"/>	Clear Width of Span	<input type="text"/>	Length of Strut	<input type="text"/>	Buried under cover?	<input type="text"/>	Depth of Cover	<input type="text"/>	Type of Strut	<input type="text"/>	Skew Angle	<input type="text"/>	Strut Condition	<input type="text"/>
Drainage Cond.	<input type="text"/>	Reset Node ID	<input type="text"/>	Notes				<input type="text"/>									
Added Length Needed? <input type="text"/> 0=None 1=1-10 2=11-20 3=21-30 4= 30+																	

- | | | | | | | | | | | | |
|--|--|-----------|-------------------|------------|--------|-------------|-------------------|--------|--------|-------------------|--------|
| <p>Type of Strut</p> <ul style="list-style-type: none"> 00= Precast Concrete Pipe 01=Bitum. Coated Corr. Metal Pipe 02=Corr. Metal Pipe 03=Concrete Box Culvert 04=Timber Culvert 05=Mortared Stone 06=Dry Stone 07=Multi Plate 08=Multi Plate Pipe Arch 09=Structural Plate Pipe Arch 10=Aluminum Pipe 11=Aluminum Multi Plate 12=Composite 13=Other 99=Unknown | <p>Condition of Strut:</p> <table border="0" style="width: 100%;"> <tr> <td style="width: 50%;">0=Unknown</td> <td style="width: 50%;">5=Marginally Fair</td> </tr> <tr> <td>1=Critical</td> <td>6=Fair</td> </tr> <tr> <td>2=Very Poor</td> <td>7=Marginally Good</td> </tr> <tr> <td>3=Poor</td> <td>8=Good</td> </tr> <tr> <td>4=Marginally Poor</td> <td>9= New</td> </tr> </table> | 0=Unknown | 5=Marginally Fair | 1=Critical | 6=Fair | 2=Very Poor | 7=Marginally Good | 3=Poor | 8=Good | 4=Marginally Poor | 9= New |
| 0=Unknown | 5=Marginally Fair | | | | | | | | | | |
| 1=Critical | 6=Fair | | | | | | | | | | |
| 2=Very Poor | 7=Marginally Good | | | | | | | | | | |
| 3=Poor | 8=Good | | | | | | | | | | |
| 4=Marginally Poor | 9= New | | | | | | | | | | |
| <p>Drainage Condition:</p> <ul style="list-style-type: none"> 0= Poor 1=Fair 2=Good | <p>Additional Length:</p> <ul style="list-style-type: none"> 0= None 1= Between 1 and 10 feet 2= Between 11 and 20 feet 3= Between 21 and 30 feet 4= More than 30 feet required. | | | | | | | | | | |

APPENDIX D

Wyoming DOT's Special Provision for Pipe Liner Installation

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WYOMING DEPARTMENT OF TRANSPORTATION

SPECIAL PROVISION FOR PIPE LINER INSTALLATION

Project No. 80-4(207)246 & 0410(10) Comb.
Walcott Jct.- Laramie
Halleck Ridge & Elk Mountain Sections (WBL)
& Hanna - Medicine Bow Road
Carbon County

REFERENCE: The 1996 edition of the STANDARD SPECIFICATIONS FOR ROAD AND BRIDGE CONSTRUCTION

DESCRIPTION: This work consists of filling an erosional void beneath an existing 1050 mm CMP with grout, and grouting the annular space between three new PVC pipe liners and three existing CMP's in accordance with the plans, Standard Specifications and this Special Provision.

MATERIALS: The grout used shall meet the following requirements:

- 1) The grout shall consist of portland cement, fly ash, fine aggregate, water, air entraining admixture and additional admixtures (optional).
- 2) The cementitious content of the grout shall be a minimum of 59 kg per cubic meter of portland cement and a minimum of 236 kg per cubic meter of fly ash.
- 3) The fine aggregate shall be in accordance with Section 703.01 - FINE AGGREGATE FOR CONCRETE of the Standard Specifications.
- 4) The grout shall have a minimum compressive strength of 2 Mpa in 28 days.
- 5) The grout shall have a maximum shrinkage of one per cent by volume and a maximum of 20 per cent total air content.
- 6) The recommended slump is 200 mm.
- 7) The minimum initial set time for the grout shall be at least 2 hours.

The mix design shall be determined by the Contractor and approved by the Engineer upon verification by the Materials Program.

A copy of the proposed grout mix design, including proportions of all ingredients and additives, along with the following minimum quantities of items shall be submitted to the Materials Program of the Wyoming Department of Transportation, through the Engineer, for approval, a minimum of 30 calendar days prior to its

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intended use.

- 1) 36 kg of fly ash
- 2) 10 kg of portland cement
- 3) 180 kg of fine aggregate
- 4) 0.5 L of each liquid or an equivalent quantity of each dry admixture

The Corrugated (smooth interior) PVC pipe liners shall be Contech A2 Liner Pipe, manufactured by Contech Construction Products Inc., P.O. Box 800, Middletown, Ohio 45042 (Regional Office- 4891 Independence Street, Suite 195, Wheat Ridge, Colorado 80033, 303/431-8999), or an approved equivalent product that meets or exceeds the A2 liner pipe strength and stiffness properties.

CONSTRUCTION: The Contractor shall submit the following at least 30 days prior to starting grouting operations or installing the PVC liner pipe.

- 1) Two copies of the PVC liner pipe manufacturer's specifications and installation procedures
- 2) The proposed pipe bracing method
- 3) The proposed grouting method
- 4) The bulkhead design

The Contractor is advised that there is surface water flow through the pipe at Station 28+436. A temporary dike will need to be constructed above the pipe inlet, and the surface water shall be pumped to the existing pipe culvert to the east prior to installing the PVC liner pipe. In addition, debris and sediment have accumulated within all three of the existing pipe culverts which shall be removed prior to installation. The existing energy dissipator at the exit end of the pipe at Station 28+529 shall be removed. The pipe liner installation and grout placement shall be accomplished during the dry season when precipitation or snowmelt flowing through the drainage will be minimal.

The liner pipe shall be installed and grouted in accordance with the manufacturer's recommendations. A factory representative from the company that manufactures the liner pipe shall be present during installation.

Prior to sliplining, the existing pipe shall be inspected, thoroughly cleaned, and the liner clearance should be verified. Any obstructions, protrusions, joint offsets, debris etc. that could damage the liner or block passage of the pipe shall be repaired or removed prior to the relining operation.

The liner pipe may be either pushed or pulled through the existing pipe. Liner pipe shall be inserted spigot into bell. The leading pipe shall be protected by

a nose piece or nose cone. A pushing or pulling ring/plate shall be used during installation. After insertion, the installed liner pipe shall be held in place to facilitate joining the next section.

The pipe jacking/pushing loads shall be monitored by the Contractor. The maximum safe compressive jacking loads outlined in the manufacturer's recommendations shall not be exceeded. Excessive force could damage the liner pipe or "telescope" pipe joints.

The method for placing the grout shall be determined by the Contractor in accordance with the manufacturer's recommendations, and approved by the Engineer. The grout shall extend the entire length of the culvert and may be placed from either or both ends of the culvert.

Joints between pipe segments shall be adequately sealed to prevent intrusion of material during the grouting operations. Exposed holes, cracks and other locations inside the existing pipe culverts where grout may escape shall be mortar tight prior to placing the grout.

Exterior bracing, between the pipe and the existing culvert, and internal supports, in the pipe, shall be provided to prevent movement of the pipe due to the forces associated with the placement of the grout. The bracing and supports shall be designed to resist the anticipated buoyancy forces. Filling the liner pipe with water can aid in preventing flotation and reduce any possible grouting effects from the heat of hydration.

The maximum allowable gaged pumping pressure shall not exceed 34.5 Kpa. Gauges to monitor grout pressure shall be attached immediately adjacent to each injection port. The grout mix shall be designed to completely fill the annular space uniformly up both sides of the liner simultaneously. Unbalanced or uneven grouting can affect liner shape, line and grade.

Provisions shall be made to displace or vent water within the annulus during grouting. The Contractor shall submit a vent plan indicating how dirty water and out-of-spec grout will be disposed of, and to limit injection pressure. Vent tubes shall be large enough not to clog or plug, and be installed in numbers adequate to not cause back pressure due to injection.

Earthen bulkheads or another approved bulkhead design shall be constructed at each end of each barrel and be of sufficient mass to fully retain the placement of grout. Material may be obtained within the Right-of-Way adjacent to the project or from a source designated by the Engineer.

The grout shall sufficiently fill the existing erosional void below the 1050 mm CMP and each barrel to the satisfaction of the Engineer. Any voids shall be minimized.

METHOD OF MEASUREMENT: Grout will be measured for payment by the cubic meter, complete, in place by the pumped volume. PVC Liner Pipe will be measured by the

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meter, complete, in place.

BASIS OF PAYMENT: Grout will be paid for at the contract unit bid price per cubic meter. PVC Liner Pipe will be paid for at the contract unit bid price per meter. Payment will be full compensation for removing the existing energy dissipator structure; removing and disposing of existing debris and sediment within the existing pipe culverts; temporarily rerouting the surface drainage; inspecting, cleaning and resealing the existing pipe culvert; furnishing and placing bulkheads; providing external bracing and internal supports; furnishing and placing the grout and liner pipe, including all labor, materials, equipment, tools and incidentals necessary to complete the work.

Payment will be made under:

<u>Pay Item</u>	<u>Pay Unit</u>
Grout	m ³
PVC Liner Pipe 750 mm	m
PVC Liner Pipe 900 mm	m

1-6-99

APPENDIX E

NYS DOT's Rehabilitation of Culvert and Storm Drain Pipe Specifications

		<i>New York State Department of Transportation</i> ENGINEERING INSTRUCTION	EI 00-000
Title: NEW STANDARD SPECIFICATION SECTION 602 REHABILITATION OF CULVERT AND STORM DRAIN PIPE AND DESIGN GUIDELINES FOR REHABILITATION TECHNIQUES			
Distribution: <input checked="" type="checkbox"/> Manufacturers (18) <input type="checkbox"/> Surveyors (33) <input checked="" type="checkbox"/> Main Office (30) <input checked="" type="checkbox"/> Consultants (34) <input checked="" type="checkbox"/> Local Govt. (31) <input type="checkbox"/> Contractors (39) <input checked="" type="checkbox"/> Regions/Agencies (32) _____		Approved: _____ P. J. Mack, Director, Technical Services Division Date	

ADMINISTRATIVE. This Engineering Instruction is effective for projects submitted for Letting on or after xxx, 2000 and will be incorporated into future versions of the NYS DOT Standard Specifications. The attached specification will be a shelf note and inserted by the Main Office.

PURPOSE. To incorporate numerous existing special specifications for rehabilitation of culverts and storm drains into the 602 Section of the Standard Specifications and provide design guidance on the selection and use of the various rehabilitation items. This standardization of specifications eliminates redundancies and inconsistencies between the special specifications.

BACKGROUND. The 602 Section has been recently vacated by the incorporation of Polymer Coated Steel Pipes into the revised 603 Standard Specifications. The revised 603 Specification was issued under EI 98-038, effective as of July 22,1999. All drainage pipe items, including Polymer Coated Pipe, are now included in the 603 Section. Section 602 will now be dedicated to the rehabilitation of culverts and storm drains.

Many culverts in New York State have reached or exceeded their anticipated design life. The primary distress has been corrosion; however, abrasion, joint separation, and side wall stress cracks and buckling are other reasons for replacing or rehabilitating pipe. This Engineering Instruction identifies the following methods to rehabilitate culverts, along with the design rationale for selecting each:

- Paving Inverts With Portland Cement Concrete (PCC)
- Lining With Shotcrete
- Lining With Polyester Formed-In-Place Pipe Liner

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- Lining With High Density Polyethylene Pipe
- Lining With Polyvinyl Chloride Pipe
- Lining With Corrugated Aluminum Structural Plate
- Lining With Corrugated Metal Pipe, (Aluminum, Aluminum Coated or Concrete Lined)
- Lining With Tunnel Liner Plate (Galvanized or Aluminum)

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DISCONTINUED SPECIFICATIONS.

18603.0501 M	Lining Existing Culvert with Concrete- Lined Corrugated Steel Pipe
18603.0511 M	Lining Existing Culvert with Corrugated Steel Pipe
18603.0521 M	Lining Existing Culvert with Corrugated Aluminum Pipe
09603.1404 M	Replace Inverts of Existing Corrugated Metal Pipe
08603.1405 M	Paving Inverts of Existing Corrugated Metal Pipe
05603.1899 M	Polyester Formed-in-Place Pipe Liner
06603.22 M	Concrete Paving for Corrugated Metal Pipe Inverts
18603.90nnnn M	Lining Existing Culvert with Corrugated Aluminum Structural Plate Pipe and/or Pipe Arch
01603.90 M	Lining Existing Culvert with Corrugated Aluminum Structural Plate Arch
06603.9802XX M	Lining Existing Culvert with Smooth Interior HDPE Pipe
06603.9803XX M	Lining Existing Culvert with Smooth Interior Optional Type Pipe
07603.9803XX M	Lining Existing Culvert with Smooth Interior Optional Type Pipe

DESIGN GUIDELINES.

1. General

Replacement of a buried pipe system is an expensive, time-consuming, labor intensive process and it will seldom be a viable alternative where detours or disruptions to traffic are unacceptable. Rehabilitation is a cost effective solution when replacement is not viable. Rehabilitation options include:

- Paving the invert with Portland Cement Concrete (PCC). This is a relatively low cost solution for rehabilitating culverts with minimal distress in the bottom one-third of the pipe. Generally, if the bottom one-third of the pipe has less than 30% perforations it can be rehabilitated by paving the invert. This is appropriate where there is no other structural deficiency in the pipe and the pipe is of sufficient size to accommodate this work. A minimum diameter of 1200 mm is recommended
- Shotcrete. This is a cost effective solution for large diameter culverts having minimal distress in sidewalls, roof, and invert, with generally less than 20% total perforations. The culvert should show no significant structural deficiencies, buckling or deformations. A minimum diameter of 1500 mm is recommended.
- Relining with new pipe. This can restore both structural and hydraulic capacity of a pipe. It is appropriate for a range of culvert diameters from 300 mm through 3000 mm. The existing pipe should be relatively free of large bulges that prevent the new pipe from freely sliding through it. If bulges exist, they need to be eliminated to accommodate the new liner pipe. Relining pipe generally comes in 6 m lengths and requires end access to accommodate insertion. When end access is limited, shorter pipe lengths may be special ordered. Manufacturers should be contacted to determine availability of short lengths. Pending availability, the specifications may need to be altered to identify the need for

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APPENDIX F

Pipe Durability

Durability can be broadly defined as the ability of a pipe to perform its function and withstand degradation. From a material standpoint, degradation can occur in the form of cracking, tearing, spalling, abrading, or corroding. However, deterioration can also include joint separation or failure, structural failure through buckling or deflection, as well as any other factors that reduce a pipe's ability to function. Durability is very important to a pipe's longevity, but is only one element of an assessment guideline. Several other factors that play a role in the deterioration of a pipe and that should be included in an assessment guideline are hydraulic capacity, joint failures, deflection, and cracking.

For those who would like to learn more about the durability of pipes there are a number of studies that have been conducted on this subject over the last 75 years and cover the subject in greater detail. In 1984, Bealey reported that 33 states and numerous researchers had published a total of 131 reports on the durability of pipe materials. Of these reports, 63% were concerned with corrugated metal pipe, 28% covered multiple pipe materials, 5% dealt with concrete, and 4% were concerned with various other issues. From Bealey's report it was apparent that in 1984 durability was an issue to more than 60% of the state transportation agencies.

Other publications on durability include *NCHRP Synthesis of Highway Practice 50: Durability of Drainage Pipe* (1978), Gift and Smith (2000), Gabriel and Moran (1998), Jackson and Subramanian (1990), Kurdziel (1988), "Symposium on the Durability of Culverts and Storm Drains" (1984), Ault and Ellor (2000), and Cerlanek and Powers (1993). The "Symposium on the Durability of Culverts and Storm Drains" (*Transportation Research Record*

1001), authored by Bealey (1984), is a state of the practice of concrete pipe durability. In addition, FHWA Report RD-97-140, *Durability Analysis of Aluminized Type 2 Corrugated Metal Pipe*, authored by Ault and Ellor (January 2000) and *NCHRP Synthesis of Highway Practice 254: Service Life of Drainage Pipe*, authored by Gabriel and Moran (1998), provide current information on pipe durability (for complete citations of all reports cited in this appendix, see References). FHWA Report RD-97-140 documents culvert durability from the findings of a literature review and from field investigations of aluminized type 2 corrugated metal culverts. The results of this study aid in the selection of pipe material and durability prediction methods. *NCHRP Synthesis 254* provides a state-of-the-practice overview of the service life of pipes. The Utah DOT and California DOT (Caltrans), as well as other transportation agencies, have developed charts to select pipes from pH and/or resistivity values. Figures F1–F3 are the charts Caltrans uses to select metal pipes. The National Corrugated Steel Pipe Association has developed industry-wide durability guidelines, which address the service life of galvanized corrugated steel pipe and supplemental coatings (Figures F4 and F5). This methodology is based on the Caltrans method, which included add-on service life for nonmetallic coatings. Figures F6 and F7 are examples of what the Utah DOT uses for metal and concrete pipe selection in corrosive situations (Welch 1974). Jenkins and Leatham (March 1988) evaluated the Utah DOT's pipe selection procedures from the standpoint of durability, stating that, "The resulting correlation between life expectancy at different ages was good." Other states also continue to use the basic charts developed in the 1970s and 1980s and update them to reflect the conversion to metric and any refinements discovered during usage.

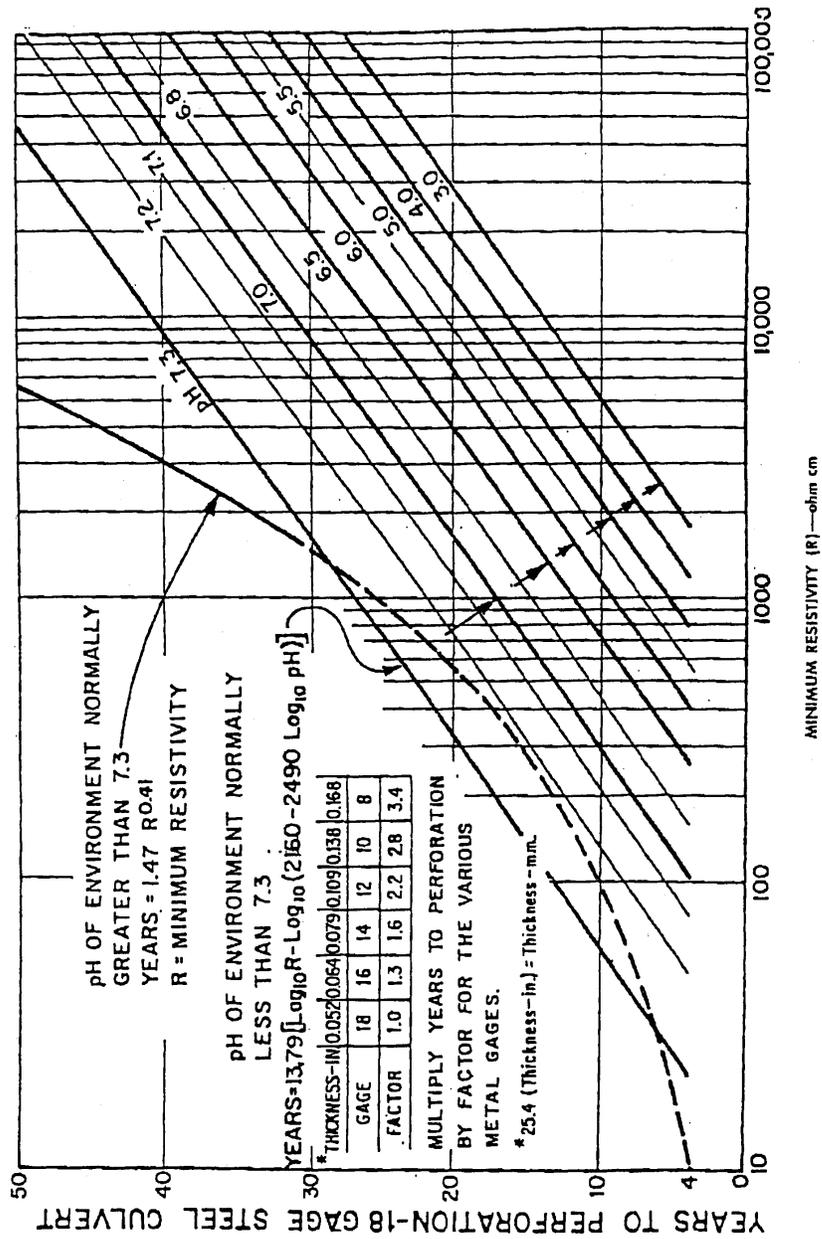


FIGURE F1 Caltrans chart for estimating years to perforation of steel culverts—California test 643 (1978) (Figure courtesy of Caltrans).

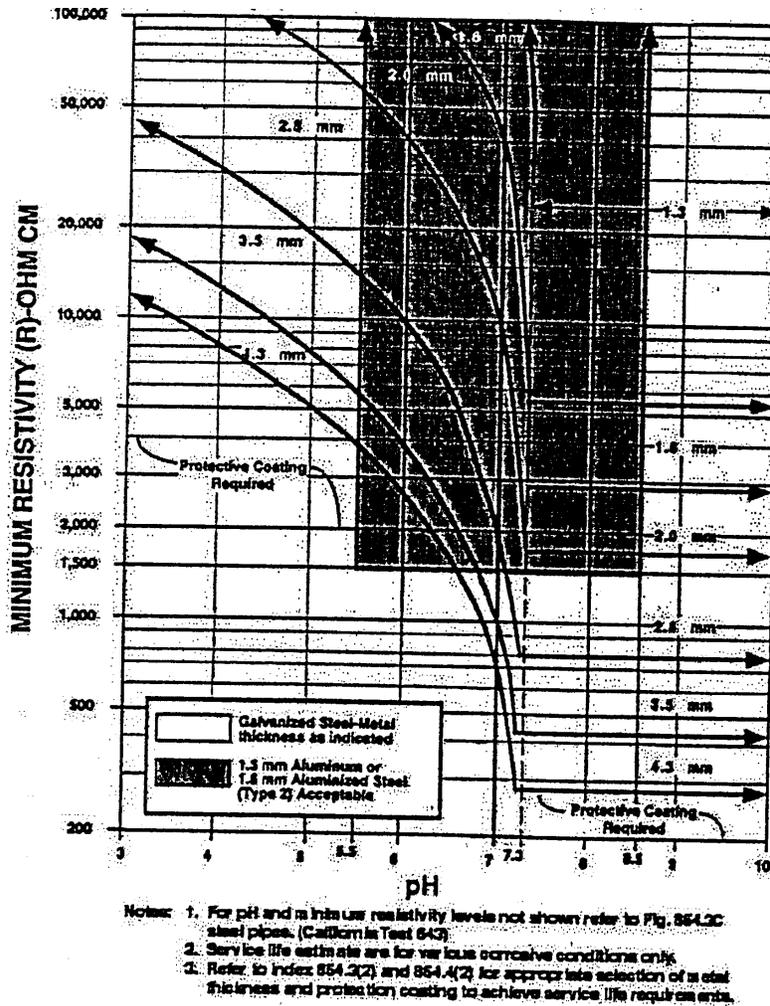


FIGURE F2 Caltrans chart for minimum thickness of metal pipe for 50-year maintenance-free service life (Figure courtesy of Caltrans).

Table 854.3A
 Guide for Anticipated Service Life Added to Steel Pipe by Abrasive Resistant Protective Coating

Flow Vel. (m/s)	Channel Materials	Bituminous Coating (yrs.) (hot-dipped)	Bituminous Coating & Paved Invert (yrs.)	Polymerized Asph. (yrs.) (hot-dipped)	Polymeric Sheet Coating (yrs.)	Composite SSRP
	Non-Abrasive	8	15	*	*	*
<1.5	Abrasive	6	15	*	*	*
1.5-4.5	Abrasive	0-6	2-12	10-40	10-40	20-50
>4.5	Abrasive	**	**	**	**	**

* Polymeric sheet coating or polymerized asphalt invert coating provides adequate abrasion resistance to meet or exceed a 50 year design service life.

** None of the listed abrasive resistant protective coatings recommended, contact District Hydraulics Branch.

FIGURE F3 Guide for anticipated service life added to steel pipe by abrasive resistant protective coating (Figure courtesy of Caltrans).

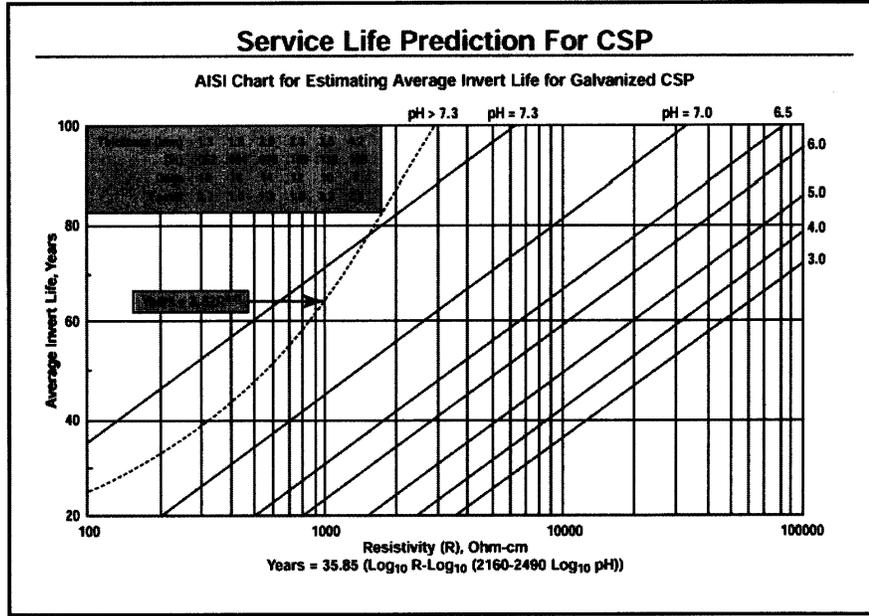


FIGURE F4 Estimated average invert life for galvanized corrugated steel pipe (Figure courtesy of the National Corrugated Steel Pipe Association).

Estimated Service Life

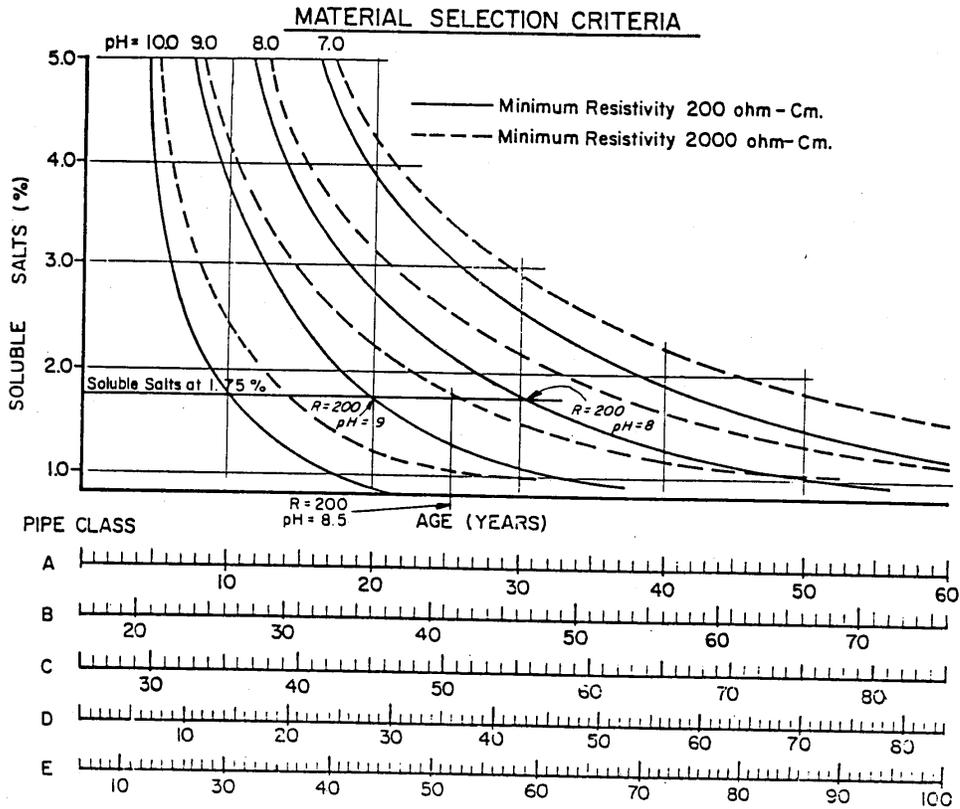
Add-On Service Life for Non-Metallic Coatings (in years)					
COATING	WATER SIDE				References
	Level 1 & 2	Level 3	Level 4	Level 4	
Asphalt Coated	10	N/R	N/R	N/R	12, 13, 14, 15, 16
Asphalt Coated and Paved	30	30	30	30	12, 13, 15, 16, 17, 18, 19
Polymerized Asphalt Invert Coated*	45	35	M/R	M/R	5, 8, 19
Polymer Precoat	80+	70	M/R	M/R	8, 19, 20, 21, 22
Polymer Precoat and Paved	80+	80+	30	30	22, 23
Polymer Precoat with Polymerized Asphalt Invert Coated	80+	80+	30	30	19, 22
Aramid Fiber Asphalt Coated	40	N/R	M/R	M/R	20
Aramid Fiber Asphalt Paved	50	40	M/R	M/R	20
High Strength Concrete Lined	75	50	M/R	M/R	10, 24
Concrete Invert Paved (75mm (3 in.) cover)	80+	80+	50	50	10, 24

N/R Not recommended

REFERENCES

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FIGURE F5 Add-on service life for non-metallic coatings (Figure courtesy of the National Corrugated Steel Pipe Association).



Pipe Class A = Plain corrugated steel pipe

Pipe Class B = Bituminous Coated Corrugated Steel Pipe, Aluminum Alloy Pipe, Galvalume Pipe, Pitch-Resin adhesive coated corrugated Steel Pipe (coated on outside only).

Pipe Class C = Asbestos Bonded Bituminous Coated Corrugated Steel Pipe, Pitch-Resin Adhesive Coated Corrugated Steel Pipe (Coated on both sides).

Pipe Class D = Plain Corrugated Steel Structural Plate Pipe.

Pipe Class E = Bituminous Coated Corrugated Steel Structural Plate Pipe, Aluminum Alloy Structural Plate Pipe.

FIGURE F6 Utah DOT material selection criteria for metal pipe (Figure courtesy of Utah DOT; extracted from UDOT-IMP-76-1).

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