Risk Assessment and Update of Inspection Procedures for Culverts

OHIO UNIVERSITY 1804

Russ College of Engineering and Technology

Ohio Research Institute for Transportation and the Environment

Prepared in cooperation with the Ohio Department of Transportation and the U.S. Department Transportation, Federal Highway Administration

Final Report
February 2005

1. Report No. FHWA/OH-2005/002	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Risk Assessment and Update of Inspection Procedures for Culverts		5. Report Date February 2005 6. Performing Organization Code
7. Author(s) Gayle F. Mitchell, Teruhisa Masada, Shad M. Sargand (ORITE), and Jobes Henderson & Associates, Inc.		8. Performing Organization Report No.
9. Performing Organization Name and Address Ohio Research Institute for Transportation and the Environment (ORITE) 114 Stocker Center Ohio University Athens OH 45701		10. Work Unit No. (TRAIS) 11. Contract or Grant No. State Job No. 14813 (0) Contract No.
12. Sponsoring Agency Name and Address Ohio Department of Transportation Office of Research and Development 1980 West Broad St Columbus OH 43223		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the Ohio Department of Transportation (ODOT) and the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

A new culvert inspection rating system was developed by ODOT and described in their 2003 Culvert Inspection Manual. ORITE developed a proposed rating system and tested it and the ODOT system on 60 culverts in 8 of 12 ODOT Districts across the state: 25 concrete culverts, 25 metal culverts, and 10 thermoplastic pipe culverts. The ODOT rating system rates 16 items on a 0 to 9 point scale, while the proposed system considers 30-33 items on the same 0 to 9 point scale. This scale represents an improvement over the 4-point (good, fair, poor, critical) scale in use in Ohio since 1982. The inspection results indicate that concrete culverts have a service life limited to 70-80 years, and metal culverts have a service life limited to 60-65 years.

A multivariable regression analysis of the inspection data found that for concrete culverts age and pH were significant factors in both rating systems, while drainage flow abrasiveness was also a significant factor in the ODOT system. For the concrete culverts, the ODOT system had a higher adjusted R^2 value and detected more significant factors; the adjusted R^2 values were 0.45 and 0.39 for the ODOT and proposed systems, respectively. A larger sample size would have improved the level of accuracy and the number of significant factors. The multivariable analysis of the metal culvert inspection data found that the significant factors were age, rise, and culvert type. Abrasiveness, pH, and flow velocity were also significant factors in the proposed system. The proposed system had a higher adjusted R^2 value and detected more significant factors; the adjusted R^2 values were 0.75 and 0.43 for the proposed and ODOT systems, respectively. The sample size of thermoplastic culverts was too small to permit a meaningful statistical analysis.

A risk assessment of the culverts was conducted based on the NCHRP Report 251 using an adjusted overall culvert rating. The adjusted ratings for the concrete culverts were between 2 and 6 in both systems, with one culvert requiring a highest priority of maintenance immediacy of action and two requiring high priority maintenance immediacies of action; the rest were rated between 4 (priority for the current season) and 6 (schedule work by the end of next season). Results for the metal culverts were similar, with the exception that only two culverts required a high level of maintenance immediacy of action. The adjusted ratings for the thermoplastic pipe culverts ranged from 6 (add to scheduled work by end of next season) to 9 (no repairs needed) in the ODOT system and from 5 (place in current season schedule at first reasonable opportunity) to 9 (no repairs needed) in the proposed system.

A number of innovative culvert rehabilitation techniques were discussed, including slip-lining, cured-in-place pipe, invert replacement using concrete or gunite, filling voids, and repairing sleeves for localized problems.

17. Key Words	18. Distribution Statement
Culvert, concrete culvert, metal culvert, thermoplastic pipe culvert, inspection procedures, risk assessment, durability, rehabilitation	No Restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	412	

RISK ASSESSMENT AND UPDATE OF INSPECTION PROCEDURES FOR CULVERTS

Final Report

May 2005

Prepared in cooperation with the Ohio Department of Transportation and the U. S. Department of Transportation, Federal Highway Administration

by

Leading Research Agency: Ohio Research Institute for Transportation and the Environment (ORITE), Russ College of Engineering and Technology, Ohio University:

Gayle F. Mitchell, Ph.D. (Neil D. Thomas Professor)
Teruhisa Masada, Ph.D. (Assoc. Professor)
Shad M. Sargand, Ph.D. (Russ Professor)
Bashar Tarawneh (Graduate Research Assistant)

and

Sub-Contractor: Jobes Henderson and Associates, Inc., Newark, Ohio:

Kenneth E. Stewart, P.E. (Project Manager)
Sandra Mapel, P.E. (Traffic Engineer)
James Roberts (Vice President)

Ohio Research Institute for Transportation and the Environment (ORITE),
Ohio University, Athens, Ohio

TABLE OF CONTENTS

Page No.

TABLE OF CONTENTS (cont'd)

Page No.

TABLE OF CONTENTS (cont'd)

Page No.

TABLE OF CONTENTS (cont'd)

Page No.

TABLE OF CONTENTS (cont'd)

Page No.

LIST OF TABLES

Page No.

LIST OF TABLES (cont'd)

Page No.

Page No.

Page No.

CHAPTER 7: STATISTICAL ANALYSIS and RISK ASSESSMENT

CHAPTER 8: CULVERT MAINTENANCE & REPLACEMENT METHODS

CHAPTER 9: SUMMARY AND CONCLUSIONS

LIST OF FIGURES

Page No.

Page No.

CHAPTER 7: STATISTICAL ANALYSIS and RISK ASSESSMENT

CHAPTER 8: CULVERT MAINTENANCE & REPLACEMENT METHODS

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The Ohio Department of Transportation (ODOT) culvert management manual (2003) defines a culvert as "any structure that conveys water or forms a passageway through an embankment and is designed to support a super-imposed earth load or other fill material plus live load with a span, diameter, or multi-cell less than 10 ft (3.1 m) when measured parallel to the centerline of the roadway." In the state of Ohio, all bridge structures with spans 10 ft (3.1 m) or greater (as measured along the centerline of the road) are required to be inspected annually. In contrast, culverts less than 10 ft (3.1 m) in span used to be inspected sporadically under varying ODOT district procedures. Periodic inspection of culverts is an essential element in a culvert management program for identifying the need for culvert maintenance, repair, or rehabilitation. Field inspection of a culvert structure can be a major task, since it involves systematic evaluations of the culvert material conditions, culvert shape and alignments, scouring at culvert ends, conditions of headwalls/wingwalls, roadway settlement, and embankment slope conditions.

A comprehensive research project focused on culvert inspection and risk assessment methods for the Ohio Department of Transportation was greatly needed. The reasons are as follows:

1. ODOT estimates that there are over 100,000 culvert structures under Ohio's priority and general highways. Many of these culverts are

inspected only sporadically, although they are either nearing or have reached their design life. There have been a few cases of culvert failure or near failure in recent years. Loss of culvert integrity could result in temporary roadway closure and considerable rehabilitation/replacement costs. Total collapse of culverts could pose a major safety risk to motorists.

2. ODOT conducted a comprehensive culvert durability study in 1982. Since that time, new coatings as well as new culvert materials have been introduced by the culvert/pipe industry. A wide variety of culvert materials, treatments, and structural designs prevalent in the short span culverts today can potentially lead to failure mechanisms that did not exist 20 years ago.

3. A new culvert research project would establish additional case histories that can be used to further verify the culvert durability methods established during the ODOT culvert durability study (ODOT, 1982).

4. The Culvert Inspection Manual issued by ODOT in 1990 incorporated the basic risk assessment method outlined in NCHRP Report No. 251 (1982). A new culvert research project would produce detailed culvert inspection data that could be used to propose a more comprehensive culvert risk assessment method for each major culvert type in Ohio.

5. ODOT published the Culvert Management Manual in 2003, which was aimed at promoting a statewide program for conducting a periodic inspection of culverts that are less than 10 ft (3.1 m) in span. The manual presented relatively detailed numerical rating systems for corrugated metal, concrete (with no protective coating), and thermoplastic pipe culvert structures. Also, the manual presented detailed numerical rating systems for the headwalls, channel, embankment slopes, and roadway surface. Validation of the culvert inspection procedures outlined in the manual was needed.

6. New sensor technology allows more accurate measurements of aqueous, soil, and pipe material characteristics in the field and laboratory, providing comprehensive and quality data collection.

7. Many state DOTs (including ODOT) are facing a large number of aging infrastructures with limited amounts of available funding. Detailed information regarding innovative techniques for repairing/replacing aging culverts would be highly beneficial to DOT personnel. These new techniques for culvert rehabilitation/placement can be tied into the "better, smarter, faster bridge" strategic initiative.

1.2 OBJECTVES

The primary objective of this project is to reduce the risk of structural failure of short-span culverts serving major highways in Ohio. This goal will be met by achieving the following two major components of the project -- 1) detailed field inspection of short-span culverts that were identified as critical structures in ODOT districts; and 2) validation of the culvert inspection and rating procedures presented in the ODOT Culvert Management Manual (ODOT 2003). Tasks of this project are divided into:

Task 1: Obtain from each ODOT district an inventory list of high-priority short-span culvert structures. Convert the data into a spreadsheet format.

Task 2: Review the FHWA's and other DOT's culvert inspection policies and procedures.

Task 3: Perform field inspections of sixty short-span culverts in Ohio, including those that are considered as high-priority structures by various ODOT district offices.

Task 4: Verify the overall effectiveness of the inspection and rating procedures presented in the ODOT Culvert Management Manual (2003).

Task 5: Perform risk assessments of the inspected culverts based on culvert characteristics and data collected.

Task 6: Evaluate and recommend the best maintenance and remedial measures for highway drainage culverts. Review new innovative techniques for culvert rehabilitation and replacement.

Task 7: Review ODOT procedures for assessing culvert durability based on field data and maintenance records.

Task 8: Perform subsurface investigation at selected culvert sites to evaluate the overall effectiveness of the cone penetration test (CPT) as a new field test method for culverts.

1.3 OUTLINE OF REPORT

Chapter 2 compiles and summarizes information from an extensive literature review of culvert inspection and risk assessment issues. Topics addressed in this chapter include culvert inspection policies and procedures, culvert durability studies, culvert risk assessment, culvert failure cases, statistical analysis of culvert data, and culvert rehabilitation/replacement techniques.

Chapter 3 describes the national survey conducted to gain insights into state/district DOTs' culvert inspection policies and procedures. The survey consisted of eighteen questions. Responses to each question are presented and discussed in detail. Also, additional information supplied by some DOTs is attached to expand the findings of the survey.

Chapter 4 presents the current ODOT culvert inspection policies and rating systems, as found in the ODOT Culvert Management Manual (2003). First, recent historical background leading to the issue of this new manual is briefly described. The new statewide culvert management policies are explained. Then, detailed visual rating systems presented in the manual are described for concrete, metal, and thermoplastic pipe culvert structures, as well as for common elements found at many highway culvert sites (for example, headwalls, channel, embankment slopes, and roadway surface).

Chapters 5 and 6 are devoted to the field inspection phase of the project. Chapter 5 presents discussions on the inventory data obtained from several ODOT district offices, the selection process used to identify sixty culvert structures for the field inspection program, the alternate (higher-resolution) culvert inspection methods proposed in the current study, the composite characteristics of the selected culverts, and typical inspection procedures implemented at each culvert site. Chapter 6 provides the comprehensive findings made during the field inspection program along with some basic (statistical) data analysis for each major culvert type.

Chapter 7 presents the analytical phase of the research project. In the first section, statistical analysis is performed using the data collected in the study to identify key parameters that have a significant influence on the highway culverts in Ohio. The analysis is repeated using first the data collected by the ODOT rating method and then the data collected by the proposed rating method to verify the overall effectiveness of the ODOT culvert rating methods. Statistical tools used in the analysis include linear and nonlinear multi-variable regression models and tests of significance. In the second section, the ODOT procedure for estimating the culvert material durability is tested using the data collected in the current study. In the third section, a risk assessment method, based on the basic method outlined in NCHRP Report 251 (1982) and the results of the statistical analysis, is proposed for each major culvert type in Ohio.

Chapter 8, prepared by the subcontractor (Jobes Henderson and Associates, Inc.), describes the current state-of-the-art and state-of-practice for culvert rehabilitation, upgrade, and replacement. The information gathered from a wide range of sources (professional journals, conference proceedings, manufacturer handbooks, and reports issued by FHWA & state DOTs, …) is used to develop this chapter. The topics covered in the chapter include invert treatment/replacement, masonry repointing, timber bracing, joint sealing, barrel reshaping, concrete lining, slip-lining, pipe jacking, pipe bursting, horizontal earth boring, tunneling, and open-cut replacement. A flow chart is included in the discussions to present guidelines for selecting proper culvert rehabilitation/ replacement methods.

Chapter 9 offers summaries and conclusions for various phases of the current research project. Chapter 10 concludes the report by offering implementation plans, which are based on the findings of the research project. Finally, several appendix sections are attached at the end of the report to provide the national survey form (Appendix A), ORITE culvert inspection forms (Appendix B, C, D), spread sheets full of culvert data collected in the study (Appendix E inside CD ROM disk), digital photographs taken at sixty culvert inspection sites (Appendix F inside CD ROM disk), engineering specifications and drawings related to various culvert rehabilitation/replacement techniques (Appendix G; prepared by the sub-contractor), and results of CPT investigations conducted at selected culvert sites (Appendix H).

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Culvert risk assessment, inspection, and durability have been important topics among transportation engineers and researchers for several decades. There is a large body of information available on these topics in the literature. The Transportation Research Board (TRB) has published many technical papers and reports on culvert related topics. The National Cooperative Highway Research Program (NCHRP) issued a report on culvert risk assessment (No. 251 in 1982) and two synthesis reports on culvert durability (No. 50 in 1978; and No. 254 in 1998). The topics of culvert risk assessment and durability are considered to be closely related.

2.2 CULVERT INSPECTION POLICIES AND PROCEDURES

According to the Culvert Management Manual issued by ODOT (ODOT, 2003), in the state of Ohio highway culverts having span between 1 and 10 ft (0.3 and 3.1 m) are recommended to be inspected once every five years. As the span decreases, the culverts become more difficult to be inspected.

NCHRP Report 303 (2002) presented results from a national survey conducted on culvert inspection policies and procedures. A total of 155 questionnaires were sent to various transportation agencies including all state departments of transportation (DOTs), a number of federal agencies, and a large number of localities, including county road commissions, county engineering departments, public works departments, and park and recreation departments. The rate of return from the 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 of all agencies was 48% (75 of 155). The questionnaire requested information about the agency's inspection program, maintenance program, record keeping, guidelines for assessment, repair and rehabilitation, material specifications, service life prediction, and management system.

Results form the survey indicated that there is no standard state and local inspection cycle being followed by transportation agencies. There was a higher percentage of state DOTs with guidelines (37%) than local agencies (33%) and federal agencies (25%). Most local agencies responding to the survey indicated that they use the guidelines outlined in FHWA's Culvert Inspection Manual (1986). From the survey it appears that most agencies with guidelines try to inspect any culvert from minimum of 12 in (305 mm) to a maximum of 8 to 10 ft (2.4 to 3.1 m) in diameter. The survey indicated that most of the transportation agencies (approximately 80%) with guidelines evaluate the ends of the culvert (inlet end, outlet end, headwalls, and wingwalls) at the same time the main barrel is inspected. Factors that the respondents considered in their guidelines are joint failure, deflection, cracking, and corrosion which are considered in a service life or durability determination. The survey results and the literature review indicated that most agencies are assessing the debris in the culvert, the scour at the ends of the culvert, the durability factors, and the physical deficiencies of the culvert. Only 9% of the survey respondents had guidance to select culvert repair methods. Only 7% of the respondents indicated that they had guidelines to select the culvert rehabilitation method. More respondents (15) indicated that they consider the following factors in their decision to rehabilitate a culvert: hydraulic capacity, traffic volume, height of fill, service life, and risk assessment. Service life was factored into the decision process by 13 responding agencies (24%). The survey indicated that 19% of the respondents had a management system that uses culvert assessment. Little work has been done on developing a culvert management system. A complete management system would involve an evaluation of the life-cycle costs, deterioration models for each culvert type and the effect of each maintenance strategy.

2.3 CULVERT RATING SYSTEM

Kurdziel (1988) reviewed the culvert condition rating systems used in durability studies conducted by various private, state, and federal agencies. He analyzed and compared the rating scales used in these studies. He noted that many rating systems lacked detailed descriptions of the levels of material distress. In order to meet his objective, he modified the FHWA's culvert rating systems (FHWA, 1985) with the information obtained from reviewing various state DOTs' data. A new material durability rating system for both metal and concrete culvert was proposed based on these comparisons.

2.4 CULVERT DURABILITY STUDIES

NCHRP Report 50 (1978) defined durability as the material's ability to resist degradation as a result of forces of chemical or electrochemical corrosion and mechanical abrasion. In culvert and storms drains, durability is a means of stating and comparing useful service lives when limited by the culvert material performance. Culvert durability is usually affected by two mechanisms – corrosion and abrasion.

NCHRP Report 254 (1998) stated that parameters most frequently related to chemical and electrochemical corrosion are soil-side and water-side pH, soil-side and water-side electrical resistivity, chemical composition (including the concentration and distribution of oxygen) of soil surrounding the culvert, and chemical and mineral composition of soil in the drainage area feeding the culvert. The report cited the usage of thermoplastic materials as a significant change, and noted that linings for metal culverts continued to encounter durability problems.

The ODOT Culvert Durability Study (ODOT, 1982) documented approximately eight thousand culverts with service life ranging from recently installed to over forty years. The majority of the culverts in the 1982 inventory were constructed of steel and concrete. The inventory provided information about the corrosion and abrasion resistance of various types of culvert and protection materials used for culverts in the state of Ohio. A total of 531 concrete pipe culverts, 386 structural steel plate pipe (SSP) culverts, and 624 corrugated steel pipe (CSP) culverts were inspected between 1972 and 1975. Of the 624 CSPs, 127 were bituminous coated (AASHTO M 190 Type A) and 302 were bituminous coated with paved inverts (AASHTO M 190 Type B and C). These culverts were nearly all 42 in (1.07 m) or larger in size. The collected data at each site included pipe size, material type, and wall thickness; type of pipe protection; depth and velocity of dry weather flow; presence of abrasive material and apparent effect; amount and type of sediment or debris or both; pH of water, streambed, and embankment; electric resistivity of water, streambed, and embankment; description of protection and protection rating; description of base pipe and base pipe rating; qualitative chemical tests; and metal cores. Detailed analyses were performed to evaluate the effects of various environmental factors on the durability of concrete pipe, galvanized corrugated steel pipe, and bituminous protection of corrugated steel pipe. Equations and graphs were presented to predict the service lives of these culvert materials. This phase of the study was in general limited to culverts with diameter or rise greater than 42 in (1.07 m). The ODOT study pointed out that the environmental conditions in Ohio were somewhat unique (or aggressive) compared to those in most other states. This is because a large area in Ohio is characterized by non-neutral pH flow and abrasive geological materials. Different factors impact service life of each culvert type. Both reinforced concrete and corrugated metal culverts are susceptible to corrosion and abrasion, depending on the type of coating and service conditions. Corrosive actions intensify under soil conditions with low pH, low resistivity, and increased moisture and temperature. Abrasive actions amplify with increased drainage flow velocities and coarser, heavier bed loads. Thermoplastic culverts are more corrosion and abrasion resistant.

Hurd (1986) evaluated the durability of concrete pipe, galvanized corrugated steel pipe, and bituminous protection corrugated steel pipe in Ohio. The data in this paper were taken from the ODOT Culvert Durability Study (ODOT, 1982). Detailed analyses were performed to evaluate the effects of various environmental factors on the durability of these materials. Water pH and abrasiveness of flow were the only environmental parameters to have a significant effect on the deterioration rate of corrugated steel pipe. Below a value of 7.0, water pH had a significant effect on concrete pipe performance. Predictive equations and graphs were presented, that can be used to estimate the service lives of concrete and corrugated steel pipe culverts. None of the environmental parameters studied had a significant effect on the performance of the bituminous protection. He concluded that the average lives of bituminous coating and coating with invert paving were 3.2 and 18.7 years, respectively, due to debonding problem they develop.

Temple and Cumbaa (1986) investigated the performance of coated and uncoated, corrugated, galvanized steel and aluminum drainage pipes in Louisiana. Ten types of metal drainage pipes were installed at each of ten locations in 1973. Test sites were selected on the basis of the pH and the electrical resistivity of the soil. One pair of each type of culvert was installed at each site. Every two years, one designated culvert of each of the pairs was removed and subjectively rated by a panel. They concluded that the 16-gauge asphalt-coated aluminum; the 14-gauge asbestos-bonded, asphalt coated galvanized steel; and the 16-gauge galvanized steel with a 12-mil (0.30-mm) interior and 5-mil (0.13-mm) exterior polyethylene coating were the test pipes with the most resistance to corrosion at the majority of the test sites. They also concluded that coatings provided more resistance to corrosion. The thicker polymeric coatings provided more protection against corrosion than the thinner polymeric coatings.

2.5 CULVERT FIELD PERFORMANCE

Hurd (1986) evaluated the 10-year performance of protective linings for concrete and galvanized steel culverts at corrosive and abrasive sites in Ohio. A total of 26 epoxy-coated concrete pipe culverts in Ohio, 57 polymeric-coated corrugated steel pipe culverts in Ohio, and 38 asbestos-bonded bituminous-coated-and-paved corrugated steel pipe culverts in Indiana, Kentucky, and Ohio were inspected one or more times between 1972 and 1986. The culvert sites were primarily located in those areas of the state that had more aggressive environmental conditions. The collected data at each site included pipe size, material type, and wall thickness; type of pipe protection; depth and velocity of dry weather flow; presence of abrasive material and apparent effect; amount and type of sediment or debris or both; pH of water; and description of protection and protection rating. Based on the field observations, the following conclusions were made regarding the performance of the protective linings. Properly applied epoxy coating provided satisfactory protection for concrete pipe at low pH sites with nonabrasive to moderately abrasive flow. Direct sunlight caused debonding of the epoxy coating. Sunlight, abrasive flow, and low pH flow all caused delamination of the polymeric coating. Asbestos-bonded bituminous coating with invert paving provided satisfactory protection of corrugated steel pipe at nonabrasive to moderately abrasive low pH sites. Abrasive flow was mainly responsible for deterioration of the asbestos-bonded bituminous coating.

Hurd (1986) collected and analyzed data concerning structural performance and durability of corrugated HDPE pipes in Ohio. A total of 172 corrugated polyethylene pipe culverts 12 through 24 in (0.30 through 0.61 m) in diameter and ranging in age from 0 to 4 years were inspected in the summer of 1985. The data collected for these pipes included, pipe diameter, cover of the pipe, type of backfill, culvert age, average daily traffic, pipe deflection, flow depth and velocity, bed load depth and particle size, water pH, and pipe slope. The data indicated that the corrugated HDPE pipes were resistant to abrasive flow. Culvert deflections stabilized within 2 to 4 years. Shallow cover and heavy truck traffic did not appear to be detrimental to the structural performance of corrugated HDPE pipe culverts. Deflection appeared to be built into the culverts instead of caused by highway loadings. Exposed culvert ends were vulnerable to damage by mowing machines and other maintenance equipment. Exposure to sunlight did not appear to affect the condition of the exposed ends. He recommended that the wall thickness of some HDPE pipe products be increased to provide greater ring stiffness.

Degler et al. (1988) analyzed field inspection data of 890 corrugated metal pipe-arch culverts in Ohio. The inspection was conducted by each of the twelve ODOT district offices. The inspection consisted of a visual examination and limited dimensional measurements. The pipe-arch was selected because this type of structure tends to have structural problems more than any other corrugated metal plate (CMP). It also represents approximately 50 percent of Ohio's CMP population. The data showed that the dominant failure/deterioration modes were heavy corrosion of plates and fasteners (27%), significant flattening of the crown (12%), and cracking of plates at corner radius bolt-line (3%). Statistical analysis was conducted to find correlation between the inspection items. The results indicated strong correlations between age and durability, between geographical location and durability, and between shape problems and crack problem. An approximately linear relationship was observed between the durability rating and age, until the age reached 35 years old, at which the durability rating worsened at more rapid rates. Culverts in southeastern Ohio had the lowest durability scores due to low pH and higher abrasion bed loads. An approximately linear relationship was observed between shape and cracking and seam cracking problem. No correlation was indicated between the depth of cover and the shape distortion, durability, or cracking problems.

Between 1994 and 1998, the Missouri Department of Transportation (MDOT, 2001) inspected 230 culverts in seventy-one counties throughout ten districts. The types of the culvert inspected included double-wall polyethylene (DWP), single-wall polyethylene (CPE), poly-liner, aluminized, aluminum, polymer coated, concrete box, poly-vinyl chloride (PVC), PVC liner, in-situ form, fiberglass, slotted drain, galvanized and reinforced concrete. All culverts were visually inspected to determine if any damage, erosion, or abrasion has occurred since they were last inspected. A picture was taken of the inlet and outlet of each pipe. Beginning in 1995, a video was taken inside the culvert to determine the condition of the joints, view any possible deflections along the length of the pipe, and discover any deterioration of the culvert itself. All videos and pictures were kept on file. Seven tests were conducted by the culvert inspection crew. These tests included soil pH, water pH, 4-pin resistance, soil box resistance, soil to pipe resistance, water hardness and pipe thickness. All these tests were conducted at the inlet end of the pipe, unless the inlet was not accessible, then the outlet end was tested. Some of these tests provided significant data; others did not. The soil to pipe resistance and water hardness did not show any consistency or trends. The hardness of the water did not affect the culvert unless it stayed for an extremely long time. Mower damage was one of the most common problems detected by the inspection crew. Another problem was deformation or indentation of the pipe. Other problems existed but they were minimal. Overall, the condition of the culverts was favorable. This study has shown correlation of field performance and service life of pipes to field testing, such as pH and soil resistivity. Other testing conducted in this study, identified neither notable trends or provided little correlation to the performance. Data collected over the years of the study has determined that, on average, steel pipe will last 40 years. Many factors affect corrosion of meal pipe, such as soil pH, water pH, soil resistivity, fertilizers, herbicides, coal cinders, and deicing salts. Seventy-six percent (76%) of the galvanized steel pipes in this study were replaced because the invert was rusted out. There was not enough information to form any statistical conclusions about the life span of plastic pipe, which is expected to last 75 years, according to its manufacturers. Like steel, concrete culverts are susceptible to corrosion and abrasion. Low pH, high level of sulfates in the soil or water, and acid run-off from mining areas can be of concern with concrete. The majority of concrete culverts had a high structural and material durability rating. It was noted that concrete culverts have demonstrated a service life of at least 75 years and very well may last 100 years, as originally predicted.

2.6 STATISTICAL ANALYSIS AND RISK ASSESSMENT

Hadipriono et al. (1988) used regression analysis to predict service life of concrete pipe culverts. Five hundred twenty-one sections of concrete culverts inspected by ODOT were used in the analyses (ODOT Culvert Durability Study, 1982). Variables considered in this study included: pipe age, pipe size, depth of flow, flow velocity, presence of abrasive materials, presence of sediment or debris, protection rating, slope of pipe, and pH level of water. The independent variables used in the analysis included: age of the pipe, rise or diameter of the pipe, flow depth, flow velocity rating, sediment depth, pipe slope, and pH of water. The dependant variable is concrete pipe rating. Two types of regression models were used. One was additive (which had a standard linear form), and the other was multiplicative. The multiplicative model used log transforms. The fact that concrete culvert rating (instead of age) was used as the dependant variable restricted the use of this model to the prediction of service lives of culvert given the knowledge of the independent variables. The results indicated an estimated expected life of 86 years for concrete culverts. Such service life estimates may be of value to engineers performing life-cycle cost studies of these types of culverts.

NCHRP 251 (1982) presented a risk assessment model for bridge substructures below the waterline. Risk assessment categories included scour, undermining, section loss, general deterioration of material, and settlement. Equation 2.1 shows the model

$$UI = IA \pm M \qquad \text{Eq. 2.1}$$

where UI = Urgency Index; IA = Initial Assessment; and M = Modification.

Appendix G of the report presented the substructures' condition below the waterline for urgency index, initial assessment and modification assessment and gave a number for each condition. The assessment modification should be algebraically added to the initial assessment to produce the maintenance urgency index. Once an urgency index is selected, the type of action to be taken in the inspection process and by maintenance forces can then be selected as shown below:

UI = 9 --- No repairs & actions needed.

UI = 8 --- No repairs needed. List special items for next regular inspection.

UI = 7 --- No immediate plans for repair. Possibly increase the level of inspection.

UI = 6 --- Add to the scheduled maintenance work by the end of the next season.

UI = 5 --- Place in the current maintenance schedule.

UI = 4 --- [Priority] Review the maintenance work schedule for the current season. Adjust it if possible.

UI = 3 --- [High Priority] Perform maintenance work as soon as possible in the current season.

UI = 2 --- [Highest Priority] Discontinue other maintenance work if required. Take emergency subsidiary actions if needed (ex. reduced load posting, one-lane traffic, no trucks)

UI = 1 --- [Emergency] Emergency actions required. Reroute traffic and close.

UI = 0 --- Close for repairs.

2.7 CULVERT FAILURES

Cowherd and Corda (1994) examined flexible metal culvert case history, including two failed cases and several non-failure cases, to evaluate the degree of deformation (flattening) that can be tolerated by these structures without failure. The data from the two failed cases indicated that the collapse had occurred at top mid-ordinate flattening of 45 to 55%. For many culverts that did not fail, the top mid-ordinate flattening varied from 22 to 34%. A correlation was established between the type of soil backfill and potential structural flattening. Based on the findings, they recommended the following action to be taken if the reduction in the top mid-ordinate is as follows:

< 20% .... No action required

20 to 25% ..... Reduced legal load to 90% of H-20. Inspect at 6 month interval

25 to 30%. ..... Reduced legal load to 75% of H-20. Inspect at 6 month interval

> 30% .... Close the road. Conduct a detailed analysis to decide the course of action.

2.8 CULVERT REHABILITATION AND REPLACEMENT TECHNIQUES

NCHRP Synthesis Report No. 303 (2002) presented comprehensive summary information on the best available technologies for culvert repair and rehabilitation. There are five levels of actions in any culvert management program:

Level 1: Routine Maintenance

Level 2: Preventive Maintenance

Level 3: Rehabilitation

Level 4: Upgrade

Level 5: Replacement

Level 1 (routine maintenance) is any basic work needed to keep the culvert in safe, functioning condition by repairing specific defects as they occur. Examples of the Level 1 actions include ditch cleaning and debris and sediment removal.

Level 2 (preventive maintenance) is any more extensive work to stop light deterioration and prevent progressive deterioration. Examples of the Level 2 actions include ditch repair, joint sealing, concrete patching and mortar repair, and scour prevention.

Level 3 (rehabilitation) consists of any extensive work performed to repair/recondition portion(s) of the culvert and extend remaining service life. Examples of the Level 3 actions include repair of headwalls and wingwalls, invert paving, repair of scour, embankment slope stabilization, streambed paving, improvement of inlet configuration, and installation of debris collectors.

Level 4 (upgrade) is any work to upgrade the condition of the culvert to a new status. Examples of the Level 4 actions include lining of the barrel, and culvert extension. There are some innovative lining techniques currently being marketed by the industry. For example, a seamless textile/thermoplastic-based liner can be inserted into the aged pipe structure, heated, and pressurized inside the pipe to expand and fit tightly to the shape of the host pipe. This technique provides a "cured-in-place" liner. A study by Johnson and Zollars (1992) at Minnesota DOT showed that culvert relining could be inexpensive and minimally disruptive.

Level 5 (replacement) consists of any major work to replace the existing culvert with a completely new culvert having a new service life. Examples of the Level 5 actions include conventional open-cut technique and new innovative trenchless techniques. The conventional open excavation method is still the primary option for replacing the underground structure. However, this method is disruptive to motorists, poses safety-hazards to the workers in the trench, may be costly (depending on the trench size), and may also create conflicts with other utility lines. The relatively new trenchless technology includes the pipe bursting (PB) method and the pipe jacking (PJ) method. In the PB method, a bursting body is pulled through the host pipe (to be replaced). The pipe wall is destroyed by static or dynamic forces applied by the bursting body. Fragments of the host pipe wall are pushed into the surrounding soil. The new pipe is then installed immediately behind the bursting body before the hole has a chance to collapse. The PB method is suitable for pipes that are made of brittle materials. In the PJ method, the pipe to be replaced is re-bored, destroyed, and conveyed by a remote control tunneling machine. The new pipe is jacked hydraulically directly behind the tunneling machine. This method is more suitable for flexible pipes that cannot be easily burst by the PB method. In both of these methods, the diameter of the new pipe can be greater than the diameter of the old pipe. Additional information on the two innovative methods can be found in a paper by Stein (1990).

CHAPTER 3: NATIONAL SURVEY

3.1 INTRODUCTION

As stated in Chapter 1, one of the tasks in the research project was to conduct a national survey on highway culvert management policies and inspection/rating procedures. Findings from this task could have implications for the other tasks and implementation plans. Since ODOT is in the initial stage of implementing new comprehensive statewide management policies and risk assessment procedures for highway culverts, the data collected from the survey could be beneficial to highlight national trends, as well as innovative and effective policies/programs practiced by some highway agencies. Literature review had indicated that some state departments of transportation (for example New York) had developed comprehensive approaches for culvert management. This chapter presents the survey methodology, descriptions of the survey questions, survey results, and additional information collected during the survey.

3.2 SURVEY METHODOLOGY

The questions on the survey were initially conceived by the ORITE researchers based on their past experience with highway culvert structures and additional insights gained through the literature review. The initial set of questions was then reviewed by the ODOT personnel, and comments were incorporated into the survey form. Once the survey form was finalized, it was sent electronically to hydraulic engineers or equivalents in DOT agencies, via the ODOT mailing list.

3.3 SURVEY QUESTIONS AND RESULTS

The survey was conducted twice during the course of the current research project. The survey form was sent out initially in June 2003. Only twenty-six (26) state DOTs responded to the initial survey. The same survey form was mailed out in April 2004 to expand the data base and obtain updates from previous respondents. Subsequent to mailing the initial survey, non-responding DOTs were contacted by follow up e-mails and telephone calls and urged to complete and return the survey. At the time of drafting this report, the total number of DOT offices that responded to the survey was forty (40), which included British Columbia, Washington D.C., and Puerto Rico – see Table 3.1.

Table 3.1: List of State/District DOT Offices Responding to National Survey

Alaska	Idaho	Michigan	New Hampshire	South Carolina	Washington
Arizona	Indiana	Minnesota	New Jersey	South Dakota	West Virginia
Arkansas	Iowa	Mississippi	New Mexico	Tennessee	Washington DC
California	Kansas	Missouri	Ohio	Texas	Puerto Rico
Connecticut	Kentucky	Montana	Oklahoma	Utah	British Columbia
Delaware	Louisiana	Nebraska	Pennsylvania	Vermont	
Hawaii	Maryland	Nevada	Rhode Island	Virginia	

The survey questionnaire consisted of a total of eighteen (18) questions. These questions can be divided into four groups – the first group (Questions #1-#2) was to gather the respondent's profile, the second group (Questions #3-#9) related to the DOT's culvert management/policies and procedures, the third group (Questions #10-#13) covered the culvert rating system, and the fourth group (Questions #14-#18) focused on risk assessment. The following sections describe the survey results from each survey question group. The questionnaire form used in the national survey is included in Appendix A.

3.3.1 Survey Questions 1 and 2

The first two questions were used to gather the basic profile of the person who is responded to the survey, which are as follows:

Question 1: What is your job title/position within the DOT?

Question 2: Have you personally inspected highway culverts?

Responses to the first two questions are summarized in Tables 3.2 and 3.3. About 48% of the respondents belonged to either bridge engineer/inspector or hydraulics engineers. The category "None of the above" included titles of administrator, structural engineer, central office operations field engineer, branch manager, pavement engineer, and planning and research division engineer. Responses to Question 2 indicated that 75% of the respondents had prior experience in inspecting highway culvert structures.

Table 3.2: Responses to Survey Question 1

What is your job title/position within the DOT?

Response to Question 1:		Number	Percentage
a	Bridge Engineer/Inspector	15	38%
b	Surveyor	0	0%
c	Hydraulic Engineer	4	10%
d	Maintenance Dept. Personnel	3	8%
e	None of the Above	16	39%
Blank (No Response)		2	5%

Table 3.3: Responses to Survey Question 2

Have you personally inspected highway culverts?

Response to Question 2:		Number	Percentage
a	Yes	30	75%
b	No	8	20%
Blank (No Response)		2	5%

3.3.2 Survey Questions 3 Through 9

The next several questions were designed to learn the current culvert management policies/practices of the agencies:

Question 3: Who performs the bulk of culvert inspections in your DOT?

Question 4: Does your DOT address Confined Space issues with regard to culverts?

Question 5: In your state, how is highway culvert defined?

Question 6: Does your DOT have any inspection policies for highway culverts?

Question 7: If the answer to Question 6 is "Yes," provide a brief explanation of the inspection guidelines/policy.

Question 8: Does your DOT's culvert inspection policy specify the frequency of culvert inspection?

Question 9: If the answer to Question 8 is "Yes," specify the frequency.

Responses to these questions are summarized in Tables 3.4 through 3.8. According to Table 3.4, a variety of personnel are performing field culvert inspections. There appears to be no one specific type of personnel who engage in the culvert inspection work in many states. The category lumped as "Others" included consultants (contractors) and maintenance personnel. According to Table 3.5, nearly half of the state/district DOTs are addressing the confined space issues. For state DOT respondents, 37 respondents (= 46%) are addressing confined space issues.

In Table 3.6, the “None of the above” category constituted the majority of the responses (85%). The responses indicated that about 60 to 70% of the state DOTs borrowed the AASHTO definition (span ≤ 20 ft or 6.1 m), as applied to culverts. Other responses included currently under development, no definitions, some type of conduit for draining water, drainage pipes, and drainage opening below a roadway embankment having no distinction between superstructure and substructure and a minimum opening size of 36 ft^2 (3.3 m^2).

According to Table 3.7, about 60% of the agencies have developed culvert inspection policies that specify the culvert inspection frequency. For just state DOTs, 54% responded affirmatively. Table 3.8 indicates that about 55% of the DOTs that responded “yes” to Question 8 specified a 1-2 year cycle for inspecting culverts. Some state DOTs reported having dual frequency requirements. For example, Minnesota DOT inspects culverts larger than 10 ft (3.1 m) in span at 1-2 year intervals and smaller culverts in a 5-year cycle. Virginia DOT stated that they inspect large culverts (span 10-20 ft or 3.1-6.1 m) every 2 years and smaller culverts at 4-year intervals. The response “Other” included 3 to 60 months, 1 to 4 years, and every 5 years. These responses to Question 8 confirm the previous finding reported in NCHRP Report No. 303 (2002) that there is no standard culvert inspection cycle being followed by all highway agencies.

Table 3.4: Responses to Survey Question 3

Who performs the bulk of culvert inspections in your DOT?

Response to Question 3:		Number	Percentage
a	Highway Workers	12	30%
b	Engineers	6	15%
c	Bridge Inspectors/Crews	3	7.5%
d	All of the Above	4	10%
e	Others	14	35%
Blank (No Response)		1	25%

Table 3.5: Responses to Survey Question 4

Does your DOT address Confined Space issues with regard to culverts?

Response to Question 4:		Number	Percentage
a	Yes	18	44%
b	No	17	43%
c	Don't Know	0	0%
Blank (No Response)		5	13%

Table 3.6: Responses to Survey Question 5

In your state, how is highway culvert defined?

Response to Question 5:		Number	Percentage
a	Span 6 ft (1.83 m) or less	2	5%
b	Span 8 ft (2.44 m) or less	0	0%
c	Span 10 ft (3.05 m) or less	1	2.5%
d	Span 15 ft (4.57 m) or less	1	2.5%
E	None of the above	34	85%
Blank (No Response)		2	5%

Table 3.7: Responses to Survey Question 6

Does your DOT have any inspection policies for highway culverts?

Response to Question 6:		Number	Percentage
a	Yes	24	60%
b	No	13	32.5%
c	Don't Know	1	2.5%
Blank (No Response)		2	5%

Table 3.8: Responses to Survey Question 8

Does your DOT's culvert inspection policy specify the frequency of culvert inspection?

Response to Question 8:		Number	Percentage
a	Yes	22	55%
b	No	6	15%
c	Don't know	1	2.5%
d	Not applicable	2	27.5%

If the answer to Question 8 is "Yes," specify the frequency.

Response to Question 8:		Number	Percentage
a	Less than 1 year	0	0%
b	1-2 years	12	48%
c	3-5 years	4	16%
d	More than 5 years	0	10%
e	Other	9	36%

3.3.3 Survey Questions 10 Through 13

The third group of questions was developed to ascertain information regarding the culvert rating systems used by the other DOTs:

Question 10: Has your DOT developed a culvert inspection manual?

Question 11: Does your DOT apply any numerical rating systems to highway culverts?

Question 12: Who developed your DOT's culvert numerical rating system?

Question 13: Does your DOT have any numerical rating systems for thermoplastic pipe inspection?

Responses to the above questions are summarized in Tables 3.9 through 3.12. From Table 3.9, only five state DOTs (Arizona, California, Connecticut, Indiana, Kansas), other than Ohio, have developed their own culvert inspection manual. Results in Table 3.10 show that 55% of respondents for 54% of the state DOTs are applying numerical rating systems to evaluate in-service conditions of highway culverts. According to Table 3.11, a little over 40% of the state DOT respondents recognize culvert numerical rating system developed by either FHWA or themselves (Washington D.C. and Puerto Rico noted using FHWA system). The category "Other" included a joint effort between a consultant and the local DOT, and a consultant. Finally, according to Table 3.12, only one state DOT (Texas) other than Ohio has developed a numerical rating system to visually evaluate thermoplastic pipe culverts.

Table 3.9: Responses to Survey Question 10

Has your DOT developed a culvert inspection manual?

Response to Question 10:		Number	Percentage
a	Yes	5	12.2%
b	No	30	75%
c	Don't Know	1	2.5%
Blank (No Response)		4	10%

Table 3.10: Responses to Survey Question 11

Does your DOT apply any numerical rating systems to highway culverts?

Response to Question 11:		Number	Percentage
a	Yes (2 non-state DOTs)	22	55%
b	No	15	37.5%
c	Don't know	1	2.5%
Blank (No Response)		2	5%

Table 3.11: Responses to Survey Question 12

Who developed your DOT's culvert numerical rating system?

Response to Question 12:		Number	Percentage
a	FHWA	11	27.5%
b	Your DOT	6	15%
c	Other *	5	12.5%
d	Don't Know	0	0%
Blank (No Response)		18	45%

Table 3.12: Responses to Survey Question 13

Does your DOT have any numerical rating systems for thermoplastic pipe inspection?

Response to Question 13:		Number	Percentage
a	Yes	1 (Texas)	2.5%
b	No	19	47.5%
c	Don't know	3	7.5%
Blank (No Response)		17	42.5%

3.3.4 Survey Questions 14 and 15

The next group of questions focused on risk assessment methods utilized by each local agency:

Question 14: Does your DOT utilize the culvert risk assessment method proposed by the NCHRP Report 251?

Question 15: Who developed your DOT's culvert risk assessment system?

Responses to these two questions are summarized in Tables 3.13 and 3.14. The results in Table 3.13 show that most state DOT personnel do not use or are not familiar with the NCHRP Report 251. Only five state DOTs have developed their own culvert risk assessment procedure (see Table 3.14). These include California, Michigan, Minnesota, Pennsylvania, and Tennessee. The response "Other" included having no risk assessment system in place, risk assessment method currently under development, and utilization of the regular NBIS criteria.

Table 3.13: Responses to Survey Question 14

Does your DOT utilize the culvert risk assessment method proposed by the NCHRP Report 251?

Response to Question 14:		Number	Percentage
a	Yes	0	0%
b	No	30	75%
c	Don't know	8	20%
Blank (No Response)		2	5%

Table 3.14: Responses to Survey Question 15

Who developed your DOT's culvert risk assessment system?

Response to Question 15:		Number	Percentage
a	Your DOT	5	12.5%
b	Other *	8	20%
c	Don't know	4	10%
Blank (No Response)		23	57.5%

3.3.5 Survey Questions 16 through 18

The remaining three questions dealt with a few remaining topics of interest, such as the development of a computer database, the decision process for culvert replacement, and the use of special inspection tools:

Question 16: Do you have a computer database for the highway culverts in your state?

Question 17: How does your DOT decide when to replace each highway culvert?

Question 18: Does your DOT or the subcontractor that you retain, utilize any special equipment to conduct visual inspection of small culverts?

Responses to the first two questions are summarized in Tables 3.15 through 3.17. According to Table 3.15, about 57% (21 out of 37) of the responding state DOTs have a computer database to manage culverts. In most cases, the database was developed mainly for culverts between 10 and 20 ft (3.1 and 6.1 m) in span. Three (Alaska, Arizona, Virginia) of the state DOTs stated that their computer database was for culverts greater than 20 ft (6.1 m) in span. New Hampshire DOT reported that only culverts 3 ft (0.9 m) or larger in span/diameter on interstate highway systems were addressed in the database. At least two (District of Columbia, Indiana) of the state/district DOTs, which currently do not have any computer database, reported that the database was under development. The database tools used by the state DOTs included ACCESS, PONTIS, and SI&A. As shown in the second part of Table 3.15, a few state DOTs are in a process of developing an innovative culvert computer database that incorporates aerial photographs, GIS, GPS, current rating, and health and priority index.

Table 3.15: Responses to Survey Question 16

Do you have a computer database for the highway culverts in your state?

Response to Question 16:		Number	Percentage
a	Yes	23 (state DOTs)	57.5% (56.8%)
b	No	15	37.5%
c	Don't know	1	2.5%
Blank (No Response)		1	2.5%

Provide additional information on your computer database.

State/District DOT	Additional Information on Computer Database
California	ACCESS database contains inventory and assessment data. Plan on using GIS and aerial photographs. Also plan on using the condition data to produce a Culvert Health Index and Priority Index for programming rehabilitation or replacement projects.
Michigan	The database is used as a reference for identifying structure size, age, and type.
Minnesota	Larger culverts (span > 10' or 3.1 m) included in the Bridge Management Office "PONTIS" database. Smaller culverts are included in the Hydraulic Office "HYDINFRA" database.
Vermont	ACCESS database stores the current rating and assessment information.
Washington	Started using GPS to track location of culverts.

Table 3.16 indicates that most state DOTs base their decision to remove existing culverts on culvert material deterioration, road surface conditions, and culvert shape (deflections). Numerical rating scores and culvert age are used much less frequently in culvert replacement decisions. The response “Other Factors” included joint conditions, fish passage issues, roadway expansion/rehabilitation/replacement, failure or imminent failure of the culvert, inadequate flow capacity, replacement criteria used for bridge class structures, and video inspection results.

Table 3.16: Responses to Survey Question 17

How does your DOT decide when to replace each highway culvert?

Responses to Question 17:		Number *	Percentage **
a	The culvert age	3	7.5%
b	The sum of numerical rating scores	9	22.5%
c	The deflections experienced by the culvert	15 (13)	37.5% (35.1%)
d	The degree of culvert material degradation	32 (30)	80% (81%)
e	The roadway surface conditions over the culvert	20 (18)	50% (48.7%)
f	Not sure	3 (2)	7.5% (5.4%)
g	Other Factors*	13 (12)	32.5% (32.4%)
Blank (No Response)		1	2.5%

* The number and % of state DOTs if different from all respondents is shown in parenthesis.

** The percentage values do not add up to 100%, since multiple responses were encouraged.

Response Item to Question 17	Observation Notes
A (culvert age)	No state DOT cited this as a sole criterion. This items was cited with items b, c, and d in a few cases.
B (numerical rating scores)	One state DOT cited this as a sole criterion. This item was often cited with items d and e.
C (deflections)	No state DOT cited this as a sole criterion. This item was always cited with item d and often mentioned with item e as well.
D (material deterioration)	Five state DOTs cited this as a sole criterion. This item was often cited with items b, c, e, and g.
E (roadway conditions)	No state DOT cited this as a sole criterion. This item was always cited with item d and often cited with item c.
F (not sure)	---
G (other factors)	Five state DOT’s cited this as a sole criterion. This item was often selected with items d and e.

Table 3.17 shows that only about 30% of the state DOTs are using special equipment to inspect small culverts. Some DOTs stated that they did not inspect any culverts smaller than 4 ft (1.2 m) (Tennessee), 5 ft (1.5 m) (New Jersey), or 6 ft (1.8 m) (Vermont) in span/diameter. Type of equipment used for small conduits by the respondents included a video camera inspection system, a robotic video camera system, and a tractor-mounted video camera (operated remotely).

Table 3.17: Responses to Survey Question 18

Does your DOT or the subcontractor that you retain, utilize any special equipment to conduct visual inspection of small culverts?

Response to Question 18:		Number *	Percentage *
a	Yes	12 (11)	30% (29.7%)
b	No	18 (17)	45% (46%)
c	Don't know	8 (7)	20% (18.9%)
Blank (No Response)		2	5% (5.4%)

* Number and percentage of state DOTs are shown in parenthesis.

3.4 ADDITIONAL INFORMATION COLLECTED DURING SURVEY

Each highway agency was encouraged to submit any documents (specifications, manuals, …) that would be relevant to various issues involved in culvert management. In some cases, supplemental documents could be located in the state/district DOT's Internet web-site. The table below lists the additional information items collected during the survey efforts. The document provided by California DOT was a visual handbook for culvert inspectors, since it contained many photographs throughout the manual to depict different levels of each field condition. However, it did not have all the relevant field conditions represented pictorially. For example, the section focusing on the rating system for headwalls had no photographs. It also was based on a coarser scale of 1 to 4. The document received from Penn DOT was mainly focused on inspection of bridge structures. It did not address inspection of culverts in great details.

Table 3.18: Additional Information Items Collected During National Survey

Source	Information Item	Related Issue(s)
California DOT	Culvert Inspection Program Handbook (revised Jan. 2004)	Inspection
Pennsylvania DOT	Bridge Safety Inspection Manual (Oct. 2002)	Inspection

CHAPTER 4: CULVERT MANAGEMENT PROGRAM IN OHIO

4.1 INTRODUCTION

ODOT has been making efforts to develop an effective culvert management program over the years. ODOT published the Culvert Inspection Manual in 1990 (ODOT 1990), which was aimed at providing a tool for a periodic inspection and rating of culverts. The manual was prepared with guidance given by previous ODOT and FHWA publications and presented relatively detailed numerical rating systems for corrugated metal culverts, concrete culverts, and masonry culverts. The numerical systems were basically a set of visual rating systems in the scale of 1 to 4 which can aid inspectors to rate the service conditions of the culverts with minimum subjective interpretation. Definitions of the scale were:

1 (Good Condition) = No repair required.

2 (Fair Condition) = Minor deficiency; Item still functioning as designed.

3 (Poor Condition) = Major deficiency; Item in need of repair to continue functioning as designed.

4 (Critical Condition) = Item no longer functioning as designed.

There are four main problems that can be identified with the 1990 manual. First, the manual did not present any numerical rating systems for headwalls/wingwalls, roadway surface, and embankment slopes. Second, the scale of 1 to 4 was not high-resolutioned enough to detect gradual deteriorations the most culverts undergo in each decade. Third, the visual rating systems in the 1990 manual were not detailed enough and specific enough to further eliminate subjectivity. Finally, the manual did not address culverts with protective coatings and culverts manufactured from thermoplastics. ODOT realized a need to develop an entirely new manual. In 2003, ODOT developed a more comprehensive manual - Culvert Management Manual.

4.2 CURRENT POLICIES

In the state of Ohio, all bridges with spans 10 ft (3.1 m) or greater are required to be inspected annually. In contrast, culverts with span from 1 to 10 ft (0.3 to 3.1 m) are to be inspected at least once every five years. For storm sewers under pavement, frequency of inspection is at least once every 5 years for spans greater than or equal to 3 ft (0.9 m). This is to assure that periodic inspections take place on all culverts and storm sewers under traveled lanes of U.S., state, and interstate state routes maintained by the ODOT.

Conducting and reporting inspections are important elements of an overall culvert inspection program. The primary objective of the culvert inspection is to do the following tasks:

1. Evaluate structural adequacy.
2. Rate culvert conditions.
3. Document the findings of the inspection.
4. Recommend corrective actions.

4.3 INVENTORY DATA

ODOT inventory data will include culverts of 12 inches (0.3 m) or greater in diameter or span. The inventory will also include storm sewers 36 inches (0.9 m) or greater in diameter or span that runs transversely under travel lanes. Figure 4.1 shows the Culvert Inventory Report form (CR-87).

4.3.1 Culvert Inventory Coding

A unique culvert file number is given for each culvert consisting of the county number, route, and culvert number. County number consists of two-digit county code summarized in Table 4.1. The three-digit number for the route is based on the main route with which the culvert is associated. The culvert number is a four-digit random number.

Entry class on ODOT CR-87 form depends on the culvert safety measures. Size, length, ability to see the opposite end, and the structure history are the factors that determine the culvert safety measures. A flow chart is provided in Figure 4.2 for determining the entry class. Class A is a non-entry inspection which involves collecting inventory and inspection information without entering the structure. Class B is a non-permit required entry, arms-length inspection performed on culverts that require no special provisions for confined space issues. Class C is an alternate entry permit required arms-length inspection performed on culvert that require an alternate entry procedure to be followed. One requirement for Class C is that the culvert does not have a known history of atmospheric or physical hazards. Class D is an entry permit required inspection performed on culvert that require the full use and implementation of permit required confined space entry procedures.

STATE OF OHIO DEPARTMENT OF TRANSPORTATION
CULVERT INVENTORY REPORT

CR-87 12-03

CULVERT FILE NUMBER		1. Entry Class	
LOCATION AND ROUTE INFORMATION			
2. District		3. County	
4. Route		5. Straight Line Mileage	
6. Latitude		7. Longitude	
8. Road ID		9. Maintenance Responsibility	
10. Feature Intersection			
CULVERT			
11. Year built		12. Number of Cells	
13. Shape		14. Material	
15. Span (in.)		16. Rise (in.)	
17. Length (ft.)		18. Gage (no.) / Wall Thickness (in.)	
19. Gage (no.) / Wall Thickness (in.)		20. Type of Protection	
21. Slope of Pipe (%)		22. Skew (degrees)	
23. Inlet End Treatment		24. Outlet End Treatment	
25. Maximum Height of Cover (ft.)		26. Modification Type	
27. Year Modified		28. Modification Material	
29. Modification Size (in.)			
EXTENSION - INLET			
30. Year Extended		31. Shape	
32. Material		33. Span (in.)	
34. Rise (in.)		35. Gage (no.) / Wall Thickness (in.)	
36. Extension Length (ft.)			
EXTENSION - OUTLET			
37. Year Extended		38. Shape	
39. Material		40. Span (in.)	
41. Rise (in.)		42. Gage (no.)/Wall Thickness (in.)	
43. Extension Length (ft.)			
HYDROLOGY / HYDRAULICS			
44. Drainage Area (acres)		45. Design Discharge (c.f.s.)	
46. Abrasive Conditions		47. pH	
48. Channel Protection (Inlet)		49. Channel Protection (Outlet)	

COMMENTS: ____________________

____

____

____

INVENTORIED BY: ____________________ DATE: ____________________

Figure 4.1: ODOT CR-87 Form

Table 4.1: County Numbers and Districts

COUNTY NUMBERS AND DISTRICTS											
No.	ABREV.	CO. - DIST.	No.	ABREV.	CO. - DIST.	No.	ABREV.	CO. - DIST.	No.	ABREV.	CO. - DIST.
1	ADA	4DAMS- 9	23	FAI	FAIRFIELD- 5	45	LIC	LICKING- 5	68	PRE	PREBLE- 8
2	ALL	4LLEN- I	24	FAY	FAYETTE- 6	46	LOG	OGAN- 7	69	PUT	PUTNAM- I
3	ASD	4SHLAND- 3	25	FRA	FRANKLIN- 6	47	LOR	LORAIN- 3			
4	ATB	4SHTABULA- 4	26	FUL	FULTON- 2	48	LUC	UCAS- 2	70	RIC	RICH LAND- 3
5	ATH	4 THENS- 10							71	ROS	ROSS- 9
6	AUG	4UGLAIZE- 7	27	GAL	GALLIA- 10	49	MAD	MADISON- 6			
			28	GEA	GEAUGA- 12	50	MAH	MAHONING- 4	72	SAN	SANDUSKY- 2
7	BEL	BELMONT- 11	29	GRE	GREENE- 8	51	MAR	MARION- 6	73	SCI	SCIOTO- 9
8	BRO	BROWN- 9	30	GUE	GUERNSEY- 5	52	MED	MEDINA- 3	74	SEN	SENECA- 2
9	BUT	WTLER-8				53	MEG	MEIGS- 10	75	SHE	HELBY- 7
			31	HAM	HAMILTON- 8	54	MER	IMERCER- 7	76	STA	STARK- 4
10	CAR	CARROLL-11	32	HAN	HANCOCK- 1	55	MIA	IMIAMI- 7	77	SUM	UMMIT- 4
11	CHP	CHAMP AIGN- 7	33	HAR	WARDIN- I	56	MOE	IMONROE- 10			
12	CLA	CLARK- 7	34	HAS	IHARRISON- 11	57	MOT	MONTGOMERY- 7	78	TRU	TRUMBULL- 4
13	CLE	CLERMONT- 8	35	HEN	WENRY- 2	58	MRG	MORGAN- 10	79	TUS	TUSCARA WAS- 11
14	CLI	CLINTON- 8	36	HIG	HIGHLAND- 9	59	MRW	MORROW-6			
15	COL	COLUMBIANA- 11	37	HOC	HOCKING- 10	60	MUS	MUSKINGUM- 5	80	UNI	UNION- 6
16	COS	COSHOCTON- 5	38	HOL	HOLMES-11						
17	CRA	CRAWFORD- 3	39	HUR	HURON- 3	61	NOB	NOBLE- 10	81	VAN	VAN WERT- 1
18	CUY	CUYAHOGA- 12							82	VIN	VINTON- 10
			40	JAC	JACKSON- 9	62	OTT	OTTAWA- 2			
19	DAR	DARKE- 7	41	JEF	JEFFERSON- 11				83	WAR	WARREN- 8
20	DEF	DEFIANCE- I				63	PAU	PAULDING- 1	84	WAS	WASHINGTON- 10
21	DEL	DELAWARE- 6	42	KNO	NOX- 5	64	PER	PERRY- 5	85	WAY	WAYNE- 3
						65	PIC	PICKAWAY- 6	86	WIL	WILLIAMS- 2
22	ERI	ERIE- 3	43	LAK	LAKE- 12	66	PIK	PIKE- 9	87	WOO	WOOD- 2
			44	LAW	LA WRENCE- 9	67	POR	PORTAGE- 4	88	WYA	WYANDOT- 1

* Class A (Non-entry Inspection) may be used on any culvert where a good view of the entire barrel may be obtained from the culvert ends.

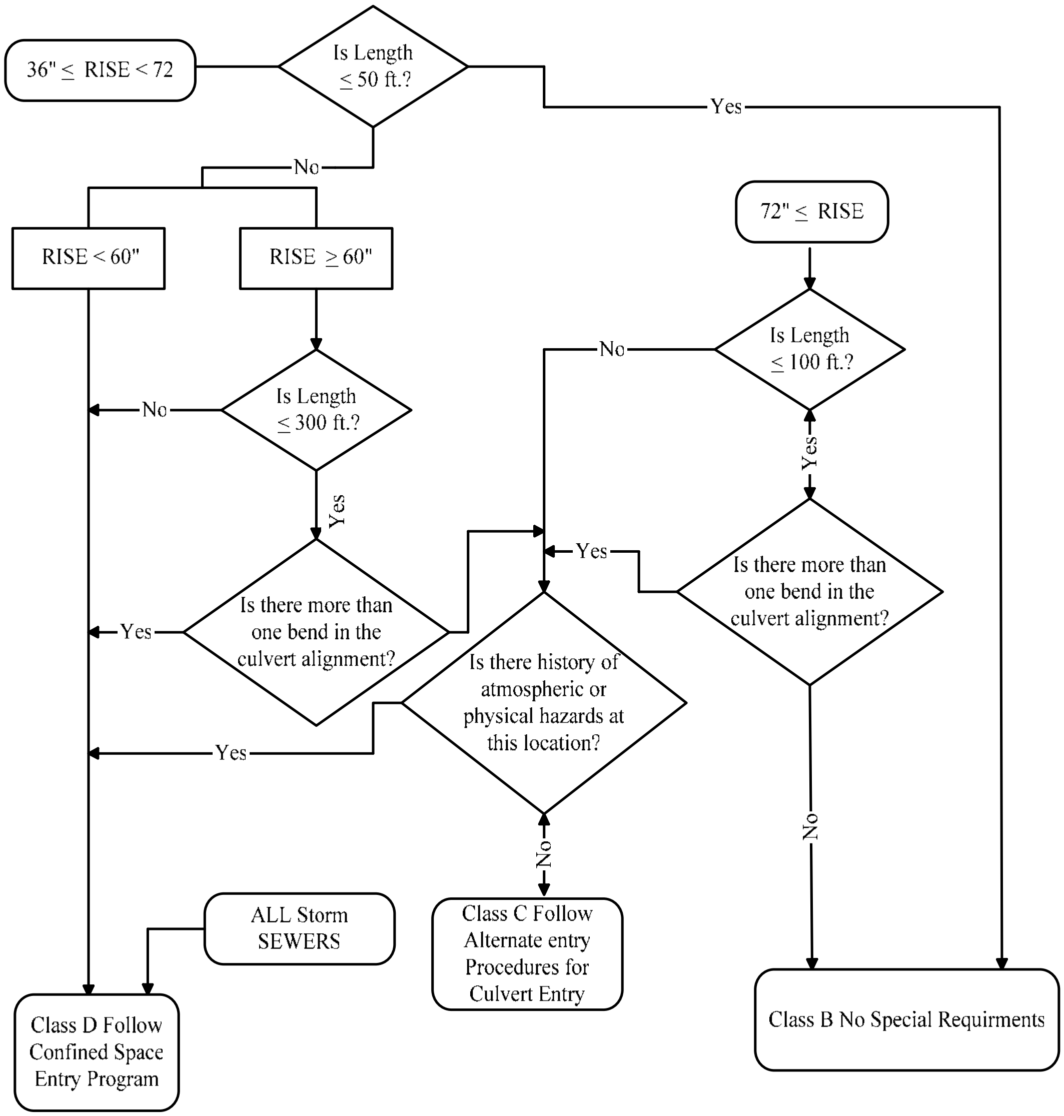


Figure 4.2: Culvert Entry Class Flow Chart

4.3.2 Location and Route Information

Location and route information on ODOT CR-87 form include:

1. District: two-digit ODOT district number in which the culvert is located.
2. County: three-letter county abbreviation as shown in Table 4.1.
3. Route: two- or three-digit route number with which the culvert is associated.

4. Straight Line Mileage: four-digit number representing the distance from the south or west county line or other beginning of the route.

5. Latitude: the latitude code in degrees, minutes, and seconds to the nearest hundredth of a second.

6. Longitude: the longitude code in degrees, minutes, and seconds to the nearest hundredth of a second.

7. Road ID: one digit code number to give road description as shown in Table 4.2.

Table 4.2: Road ID

Code	Description
1	Side Road Left
2	Side Road Right
3	Left Lane of Divided Highway
4	Right Lane of Divided Highway
5	Ramp to the Left
6	Ramp to the Right
7	Pipe Abandoned (still in place)
Blank	Mainline

8. Maintenance Responsibility: one letter to describe who is responsible for the maintenance, as shown in Table 4.3.

9. Intersection Features: such as streams, canals, and tributaries.

Table 4.3: Maintenance Responsibility

Code	Description
S	State Department of Transportation
C	County Agency
T	Township
M	City or Municipality
N	Department of Natural Resources
O	Other

4.3.3 Culvert

Culvert information on ODOT CR-87 form includes:

1. Year Built: the actual year when the culvert was installed.
2. Number of Cells: the actual number of cells the culvert consists of.
3. Shape: the shape of the culvert excluding the extensions, Table 4.4 shows the codes and descriptions.

Table 4.4: Culvert Shapes

Code	Description
01	Circular
02	Elliptical-Horizontal
03	Elliptical-Vertical
04	Pipe Arch
05	Pipe Arch, Sec. Plate
06	Arch
07	Box Culvert
08	Slab Top Culvert
99	Other

4. Material: the culvert material excluding the extensions. Table 4.5 shows the codes and descriptions.
5. Span: the distance between the two inside faces of the barrel walls (in case of the slab type culvert, span is measured from inside face to inside face of the abutment walls) measured perpendicular to the centerline of the culvert.
6. Rise: the maximum rise of the culvert to the nearest inch.
7. Gage/Wall Thickness: the gage number for metal structures or wall thickness for concrete, clay, or thermoplastic structures. Table 4.6 shows the gage number and thickness in inches and millimeters.

Table 4.5: Culvert Material

Code	Description
01	Plain or Reinforced Concrete
02	Corrugated Metal, Pipe
03	Corrugated Metal, Non-sectional Plate
04	Corrugated Metal, Sectional Plate
05	Vitrified Clay
06	Cast Iron or Ductile Iron
07	Corrugate Stainless Steel, Non-Sectional Plate
08	Corrugate Stainless Steel, Sectional Plate
09	Corrugated Aluminum Alloy
10	Brick
11	Field Tile (Clay)
12	Corrugated Plastic
13	Corrugated Plastic Smooth Interior
14	Steel Casting
15	Stone
16	Timber
17	Polyvinyl Chloride
18	High Density Polyethylene Liner
19	Corrugated Steel Spiral Rib
20	Corrugated Aluminum Spiral Rib
99	Special Item not Listed

Table 4.6: Gage/Wall Thickness

Gage	Inches	mm
16	0.064	1.63
14	0.079	2.01
12	0.109	2.77
10	0.138	3.51
08	0.168	4.27
07	0.188	4.78
05	0.218	5.54
03	0.249	6.32
01	0.280	7.11

8. Type of Protection Inside Culvert: Table 4.7 shows the codes and descriptions for the protection type.

9. Culvert Slope: the slope of culvert in percent to the nearest tenth.

10. Inlet and Outlet End Treatment: the type of end treatment for inlet and outlet. Table 4.8 shows codes and description for end treatment type.

11. Maximum Height of Cover: the cover height from the top of the culvert to the top of the pavement or embankment surface.

12. Modification Type: any modification made to the culvert without any complete removal. Table 4.9 shows the codes and descriptions for the modifications.

Table 4.7: Type of Protection

Code	Description
01	Unprotected
02	Galvanized
03	Half Bituminous Coated
04	Fully Bituminous Coated
05	Half Bituminous Coated and Paved
06	Fully Bituminous Coated and Paved
07	Asbestos Bond Coated
08	Asbestos Bond Coated and Paved
09	Vitrified Lined
10	Field Paved
11	Coal Tar Resin
12	Thermoplastic Coated
13	Aluminum Coated
99	Special Item not Listed

Table 4.8: Inlet and Outlet End Treatment Type

Code	Description
01	Full Height Concrete Headwall
02	Half Height Concrete Headwall
03	Third Height Concrete Wall
04	Stone
05	Wood
06	Metal
07	Catch Basin
08	Inlet
09	Manhole
10	Mitered End
OO	Other
UU	Unknown
NN	None N/A

Table 4.9: Modification Type

Code	Description
R	Relining original conduit.
P	Field Paving of the conduit invert.
S	Replacing or adding sections or structural plates (within original length).
B	Installing internal bands at joints or other areas.
O	Other modifications.

13. Year Modified: the year of major repair or rehabilitation of the culvert.

14. Modification Material: Table 4.10 shows the code and description for each material modification.

Table 4.10: Modification Material

Code	Description
01	Plain or Reinforced Concrete
02	Corrugated Steel Conduit
03	Corrugated Steel Structural Plate
04	Corrugated Steel Spiral Rib
05	Corrugated Steel Flanged Liner Plates
06	Corrugated Aluminum Alloy Conduit
07	Corrugated Aluminum Alloy Structural Plate
08	Corrugated Aluminum Spiral Rib
09	Thermoplastic Pipe Liner (PVC or HDPE)
10	Folded PVC Liner
11	Cured in Place PVC Liner
12	Steel Casing Pipe
99	Other

15. Modification Size: this measurement will vary with the type of modification performed. Table 4.11 shows the modification type and measurements.

Table 4.11: Modification Size

Modification Type	Measurement
Relining original conduit	Internal Diameter
Field Paving of the conduit invert	Thickness of paving
Replacing or adding sections or structural plates	Gage of Plates
Installing internal bands at joint or other areas	Internal diameter at bands

4.3.4 Extension-Inlet and Extension-Outlet

Those two sections in the ODOT CR-87 form require culvert shape, material, rise (in.), span (in.), extension length, gage (no.)/wall thickness (in.), and year of extension.

4.3.5 Hydrology / Hydraulics

Hydrology/hydraulics information in ODOT CR-87 form includes:

1. Drainage Area: total area draining through the culvert in acres.
2. Design Discharge: culvert design flow rate in ft^3/sec.
3. Abrasive Condition, the presence of granular material accompanied with stream gradient or sufficient flow to cause movement of the granular material in the streambed. Codes are Y and N for abrasive and nonabrasive condition, respectively.
4. pH: the value of water pH at the inlet of the culvert to the nearest tenth.
5. Channel Protection (Inlet and Outlet): channel protection placed by design or for maintenance purposes. Table 4.12 shows the code and description for each type of channel protection.

Table 4.12: Channel Protection (Inlet and Outlet)

Code	Description
1	Concrete Rip Rap Slab
2	Dumped Rock or Rock Channel Protection
3	Sheet Piling
4	Piling
5	Grouted Rip Rap
6	Gabions (wire mesh baskets filled with stone)
7	Fabric Bags filled with concrete or sand
8	Tied Concrete Block Mat
9	Interlock Precast Concrete Block
0	Other
X	Not Applicable
A	Precast Concrete Panels
B	Earthen Dikes
G	Grass or Brush (Naturally occurring)
V	Vegetation (Designed Soil Bioengineering)
N	None

4.4 INSPECTION GUIDELINES

A logical sequence of inspection will save steps and time. Before conducting field inspection, an office review is necessary to review any available information and safety concerns.

Field inspection starts with general observations of the overall condition of the structure and the roadway. The inspection process starts at the outlet of the culvert and inspect the embankment, waterway, headwall, wingwalls, and culvert barrel. Then, the inspector should move to the inlet of the culvert. Culvert barrels should be inspected for cross sectional shape and barrel defects such as joints defects, seam defects, plate buckling, lateral shifting, missing bolts, corrosion, excessive abrasion, material defects, and localized construction damage.

Stationing and orientation in sectional culverts are referenced by using culvert joints as stations. Stationing should start with number one at the outlet and increase toward the inlet. Location of points on circular cross section is referenced as hour on a clock. The clock should be oriented looking upstream. On the structural plate corrugated metal culverts, points are referenced to bolted circumferential and longitudinal seams.

4.5 CULVERT RATING SYSTEMS

Culvert inspection guidelines provide a starting point for culvert evaluation. The inspecting team needs to use their judgment in assigning the appropriate numerical rating. Inspector should select the lowest rating which best describes either the shape condition or the barrel condition. The following sections in this chapter present the sixteen coded items in the ODOT Culvert Inspection Report form (CR-86), shown in Figure 4.3

4.5.1 General Conditions of Culvert Material

This item evaluates culvert for:

1. Deterioration: this is the ability of the material to resist corrosion and abrasion. Corrosion is the destruction of culvert material by chemical action. Commonly, corrosion attacks metal culverts, or the reinforcement in concrete culverts, as the process of metals returning to their native state of oxides or salts. Similar processes can occur to the cement in concrete culvert if subjected to highly alkaline soils or other extremely harsh environments. Abrasion is the gradual wearing away of the culvert wall due to the impingement of bedload and suspended material. Corrosion and abrasion can

seriously affect the culvert performance, which is a common cause for culvert replacement.

2. Cracks: concrete culverts are expected to have hairline cracks (less than 1/8 inch or 3 mm). Poor side support can cause longitudinal flexure cracks (at 3, 6, 9, and 12 o'clock positions) and poor haunch support can cause shear cracks (at 5 and 7 o'clock position). Also, shear forces from above the structure can cause cracks at 11 and 1 o'clock positions. Transverse cracks may occur as a result of non-uniform bedding or fill material. In metal structures, cracks occur along bolt holes of longitudinal seams. These cracks can cause serious problems if they are associated with significant deflection, distortion, and other conditions related to backfill or soil problems. Thermoplastic pipes experience a split (rip, tear, or crack) in the wall material other than at the designated joints.

3. Dents and Localized Damage: for flexible pipe, wall damage such as dents, bulges, creases, cracks, and tears can cause a serious problem if the defects are extensive. Tables 4.13 to 4.16 show the general rating (Item No.1 on the CR-86 form) for the corrugated metal, concrete, masonry, and plastic pipe culverts, respectively.

STATE OF OHIO DEPARTMENT OF TRANSPORTATION
CULVERT INSPECTION REPORT

CR-86 12-03

CULVERT FILE NUMBER CULVERT NUMBER ______ ______ ______ ______ YEAR BUILT__________
CO ROUTE SLM ID

DISTRICT________SHAPE ________ MATERIAL __________________ LENGTH______

MAX. HEIGHT OF COVER______FEATURE INT. ______________________________

LATITUDE ____________________________ LONGITUDE ______________________

ENTRY CLASS NUMBER of CELLS

CULVERT			
1. General		2. Culvert Alignment	
3. Shape		4. Seams or Joints	
5. Slab		6. Abutments	
7. Headwalls		8. End Structure	
CHANNEL			
9. Channel Alignment		10. Protection	
11. Culvert Waterway Blockage		12. Scour	
APPROACHES			
13. Pavement		14. Guardrail	
15. Embankment			
16. Level of Inspection		**GENERAL APPRAISAL& OPERATIONAL STATUS**	

RECOMMENDED REPAIR CODE(S): COMMENTS: ________________________________

COMMENTS: ____

INSPECTED BY:______________ DATE: ____________ REVIEWED BY:______________ DATE: __________

Figure 4.3: ODOT CR-86 Form

Table 4.13: General-Corrugated Metal Culvert

Code	Category	Description
9	Excellent	New condition; galvanizing intact; no corrosion.
8	Very Good	Discoloration of surface; galvanizing partially gone along invert but no layer of rust.
7	Good	Discoloration of surface, galvanizing gone along invert but no layers of rust. Minor pinholes (with an area less than 3 square inches per square foot) in pipe material located at ends of pipe (length not to exceed 4 feet and not located beneath roadway).
6	Satisfactory	Galvanizing gone along invert with layers of rust. Sporadic pitting of invert. Minor pinholes (with an area less than 6 square inches per square foot, 4%) in pipe material located at ends of pipe (length not to exceed 4 feet and not located beneath roadway).
5	Fair	Heavy rust and scale. Pinholes (with an area less than 15 square inches per square foot, 10%) throughout pipe material. Section loss and perorations at ends. Holes in metal at end in invert and not located under roadway.
4	Poor	Extensive heavy rust; thick and scaling rust throughout pipe; deep pitting; perforations throughout invert with an area less than 30 square inches per square foot, 20%. Overall thin metal, which allows for an easy puncture with chipping hammer.
3	Serious	Extensive heavy rust; thick and scaling rust throughout pipe; deep pitting. Perforations throughout invert with an area less than 36 square inches per square foot, 25%. Overall thin metal, which allows for an easy puncture with chipping hammer. End section corroded away.
2	Critical	Perforations throughout invert with an area greater than 36 square inches per square foot, 25%.
1	Imminent	Pipe partially collapsed.
0	Failed	Total failure of pipe.

Table 4.14: General-Concrete Culvert

Code	Category	Description
9	Excellent	New condition, superficial and isolated damage from construction.
8	Very Good	Hairline cracking without rust staining or delaminations; surface in good condition; isolated damage form construction.
7	Good	Hairline cracking. No single crack greater than 1/16 inch without rust staining parallel to the direction of traffic; light scaling on less than 10% of exposed area less than 1/8 inch deep. Delaminated/ spalled area less than 1% of surface area. [Note] Cast-in-place box culverts may have a single large crack (less than 3/16 inch) n each surface parallel to the direction of traffic.
6	Satisfactory	Hairline map cracking combined with molted areas. Cracks less than 1/8 inch parallel to traffic with minor efflorescence or minor amounts of leakage. Scaling on less than 20% of exposed area less than ¼ inches deep. Spalled areas with exposed reinforcing less than 5%. Additional delaminated/ spalled areas les than 5% of surface area.
5	Fair	Map cracking. Cracks less than 1/8 inch parallel to traffic, less than 1/16 inch transverse to traffic with efflorescence and/or rust stain, leakage and molted areas. Scaling on less than 30% of exposed area less than 3/16 inch deep. Spalled areas with exposed reinforcing less than 10%. Total delaminated/ spalled areas less than 15% of surface area.
4	Poor	Transverse cracks open greater than 1/8 inch with efflorescence and rust staining. Spalling at numerous locations; extensive surface scaling on invert greater than ½ inch. Extensive cracking with cracks open more than 1/8 inch with efflorescence; spalling has caused exposure of heavily corroded reinforcing steel on bottom or top slab; extensive surface scaling on invert greater than ¾ inch. (approximately 50% of culvert is affected)
3	Serious	Extensive cracking with spalling, delaminations, and slight differential movement; scaling has exposed all surfaces of the reinforcing steel in bottom to top slab or invert (approximately all exposed surface are 50% loss of wall thickness at invert; concrete very soft
2	Critical	Full depth holes. Extensive cracking greater than ½ inch. Spalled areas with exposed reinforcing greater than 25%. Total delaminated, spalled, and punky concrete areas are greater than 50% of surface area. Reinforcing steel bars have extensive section loss and perimeter of bar in completely exposed. (Several bars in a row)
1	Imminent Failure	Culvert partially collapsed or collapse in imminent
0	Failed	The culvert in collapsed

Table 4.15: General- Masonry Structure

Code	Category	Description
9	Excellent	New conditions
8	Very Good	No cracking, no missing dislocated masonry present; surface in good condition
7	Good	Surface deterioration at isolated locations
6	Satisfactory	Minor cracking of masonry units
5	Fair	Minor cracking; slight dislocation of masonry units; large areas of surface scaling. Split or cracked stones. Minor cracking; slight dislocation of masonry units; large areas of surface scaling
4	Poor	Significant displacement of individual masonry unit
3	Serious	Extensive cracking with spalling, delaminations and slight differential movement; scaling has exposed reinforcing steel in bottom to top slab or invert; individual masonry units in lower part of structure missing or crushed.
2	Critical	Individual masonry units in lower part of structure missing, or crushed individual masonry units in top of culvert missing or crushed.
1	Imminent Failure	Structure partially collapsed or collapse is imminent.
0	Failed	Total failure of structure.

Table 4.16: General- Plastic Culvert

Code	Category	Description
9	Excellent	No signs of distress, no discoloration.
8	Very Good	Isolated rip or tear (no larger than 6 inches) caused by floating debris or construction. Minor discoloration at isolated locations.
7	Good	Split (no larger than 6 inches, not open more than ¼ inches) at two or three locations. Damage (cuts, gouges, burnt edges or distortion) to end sections from construction or maintenance. Perforations caused by abrasion located within 5 feet of outlet and not located under roadway.
6	Satisfactory	Split (larger than 6 inches, width not to exceed ½ inches) at two or three locations. Damage (cuts, gouges, burnt edges or distortion) to end sections from construction or maintenance. Perforations caused by abrasion located within 5 feet of outlet and not located under roadway.
5	Fair	Split (larger than 6 inches, width exceeding ½ inches) at two or three locations. Damage (cuts, gouges, burnt edges or distortion) to end sections from construction or maintenance. Perforations caused by abrasion located within 5 feet of outlet and not located under roadway. Fire damage beneath roadway causing distortion greater than 18 inch in diameter.
4	Poor	Split (larger than 6 inches, width exceeding ½ inches) at several locations. Split causing loses of backfill material. Perforations caused by abrasion located throughout the pipe. Fire damage beneath roadway causing distortion greater than 18 inch in diameter.
3	Serious	Split (larger than 6 inches, width exceeding 1 inch) at several locations. Split causing loses of backfill material. Section loses caused by abrasion located throughout the pipe. Fire damage beneath roadway causing holes greater than 12 inches in diameter.
2	Critical	Invert eroded away (with section 2 foot in length and ½ foot in width) throughout pipe. Fire damage beneath roadway causing holes and melting large sections of pipe.
1	Imminent Failure	Pipe Partially collapsed or collapse is imminent
0	Failed	Total failure of pipe.

4.5.2 Culvert Alignment

Culvert alignment rating evaluates the longitudinal irregularities of the barrel. It is used for precast concrete culvert segments, corrugated metal culvert that has been coupled together, and plastic pipe. The culvert barrel has to be inspected for discontinuities and settlement between adjacent culvert segments. Culvert misalignment may indicate the presence of serious problems in the supporting soil. Tables 4.17 and 4.18 present the rating for concrete, corrugated metal, plastic, and masonry structure alignment (Item No. 2 on the CR-86 form).

Table 4.17: Alignment- Concrete, Corrugated Metal and Plastic Structure

Code	Category	Description
9	Excellent	Straight line between sections.
8	Very Good	Minor settlement or misalignment.
7	Good	Minor misalignment at joints; offsets less than ½ inch; no fill, no settlement. Minor settlement or misalignment, ponding less than 3 inches
6	Satisfactory	Fair; minor misalignment and settlement at isolated location. Moderate settlement or misalignment, ponding between 3 and 5 inches.
5	Fair	Minor misalignment or settlement throughout culvert. Ponding (depth less than 5 inches) of water due to sagging or misalignment of pipe sections, end sections dislocated and about to drop off. Four or more sections with offset less than 3 inches
4	Poor	Significant settlement and misalignment of pipe; significant ponding (depths less than 6 inches) of water due to sagging or misalignment of pipe sections, end sections dislocated and about to drop off. Four or more sections with offset less than 4 inches. Rotation of foundation
3	Serious	Significant ponding (depths greater than 6 inches) of water due to sagging or misalignment of pipe sections; end sections drop off has occurred; four or more sections with offset less than 4 inches.
2	Critical	Culvert not functioning due to alignment problems throughout.
1	Imminent Failure	Culvert partially collapsed or collapse in imminent.
0	Failed	Culvert collapsed.

Table 4.18: Alignment- Masonry Structures

Code	Category	Description
9	Excellent	New conditions.
8	Very Good	Straight line between masonry units.
7	Good	Generally good; minor misalignment at joints; no settlement.
6	Satisfactory	Fair; minor misalignment or settlement.
5	Fair	Generally fair; minor misalignment or settlement.
4	Poor	Marginal; significant settlement and misalignment.
3	Serious	Poor with significant ponding of water due to sagging or misaligned masonry units; end section drop off has occurred.
2	Critical	Critical; culvert not functioning due to severe misalignment.
1	Imminent Failure	Structure partially collapsed or collapse is imminent.
0	Failed	Structure collapsed.

4.5.3 Culvert Shape

Shape rating is used for flexible structures only. The culvert barrel should be inspected for flattening, buckling, bulging, and out of roundness. In case of the presence of distortion or curve flattening, the extent of the flattened area, in terms of arc length, length of culvert affected, and the location of the flattened area should be describe in the inspection report. Length of the chord across the flattened area and the mid-ordinate of the chord should be measured and recorded. These measurements can be used to calculate the curvature of the flattened area. For culvert structures under shallow cover, the inspector should make observation of the culvert with a few live loads passing over. Tables 4.19 and 4.20 present the shape rating for corrugated metal and plastic pipe culverts, respectively (Item No.3 on the CR-86 form).

Table 4.19: Shape- Corrugated Metal Culverts

Code	Category	Description
9	Excellent	New condition; may exhibit minor damage along edge of inlet or outlet due to construction.
8	Very Good	Smooth curvature in barrel; span dimension within 1% of design.
7	Good	Top half of pipe smooth but minor flattening of bottom; span dimension within 2.5% of design.
6	Satisfactory	Smooth curvature in top half, bottom flat, span dimension up to5% greater than design.
5	Fair	Generally fair, significant distortion in top in one location; bottom has slight reverse curvature in one location but generally fair, span dimension up to 10% greater than design. Non-symmetric shape.
4	Poor	Marginal significant distortion throughout length of pipe, lower third may be kinked, span dimension up to 15% greater than design, noticeable dip in guardrail over pipe.
3	Serious	Poor, extreme deflection at isolated locations, flattening at top of arch or crown; bottom has reverse curvature throughout; span dimension more than 15% greater than design. Extreme non-symmetric shape.
2	Critical	Critical, extreme distortion and deflection throughout pipe; span dimension more than 20% greater than design critical.
1	Imminent Failure	Structure partially collapsed with crown in reverse curve.
0	Failed	Structure collapsed.

Table 4.20: Shape- Plastic Pipe Culvert

Code	Category	Description
9	Excellent	Smooth wall, deflection less than 2% from the original shape.
8	Very Good	Smooth wall, deflection less than 5% from original shape.
7	Good	Relatively smooth wall, deflection less than 5% from original shape.
6	Satisfactory	Minor dimpling appearing at isolated small area (less than 1/16 of circumference area and 1 foot in length). Dimpling less than ¼ inch deep. Pipe deflection less than 10% from original.
5	Fair	Minor dimpling appearing over 1/16 to 1/8 of circumference area and 2 feet in length. Dimples between ¼ and ½ inch deep. Pipe deflection less than 12.5% from original shape.
4	Poor	Wall crushing or hinging occurring with lengths less than 3 feet. Pipe deflection less than 15% from original shape.
3	Serious	Wall crushing or hinging occurring with lengths less than 3 feet. Moderate degree of dimpling appearing. Dimples more than ½ inch deep. Wall tearing/ cracking in the buckled region. Pipe deflection less than 20% from original shape.
2	Critical	Wall crushing or hinging occurring over the majority of the length of pipe under the roadway. Moderate degree of dimpling appearing. Dimples more than ½ deep. Wall tearing/ cracking in the buckled region. Pipe deflection greater than 20% from original shape. Sever dimpling accompanied with wall splits.
1	Imminent Failure	Pipe partially collapsed or collapsed is imminent.
0	Failed	Total failure of pipe.

4.5.4 Seams and Joints

Seams and joints rating include joints opening, seepage at joints, and surface sinkholes over the culvert. Indications of backfill infiltration and water exfiltration are the main factors to look for in joints and seams inspection. Seepage along the outside barrel can remove the supporting material. This process is called “piping.” Piping can also occur through open joints. Piping can be controlled by reducing the amount and velocity of water seeping along the outside barrel of the culvert. This requires watertight joint and anti-seep collars in some cases. Defects in seams in structural plate culverts include loose fasteners, cocked and cusped seams, seam cracking, and bolt tipping. Tables 4.21 and 4.22 present the seams and joints rating for corrugated metal, concrete, plastic, and masonry culverts, respectively (Item No. 4 on the CR-86 form).

Table 4.21: Seams or Joints-Corrugated Metal, Multi-Plate

Code	Category	Description
9	Excellent	Minor amounts of efflorescence or staining.
8	Very Good	Light surface rust on bolts due to loss of galvanizing, efflorescence staining.
7	Good	Metal has cracking on each side of the bolt hole less than 3 in a seam section. Minor seam openings less than 1/8 inch. Potential for backfill infiltration. More than 2 missing bolt in a row. Rust scale around bolts.
6	Satisfactory	Evidence of backfill infiltration through seams
5	Fair	Moderate cracking at bolt holes along a seam in one section. Backfill being lost through seam causing slight deflection. More than 6 missing bolt in a row or 20% along the total seam.
4	Poor	Major cracking of seam near crown. Infiltration of backfill causing major deflection. Partial cocked and cusped seams. 10% section loss to bolt heads along seams.
3	Serious	Longitudinal cocked and cusped seams and / or metal has 3 inch crack on each side of the bolt hole run total length of culvert. Missing or tipping bolts.
2	Critical	Seam cracked from bolt to bolt; significant amounts of backfill infiltration.
1	Imminent Failure	Pipe Partially collapsed or collapse is imminent.
0	Failed	Total failure of pipe.

Table 4.22: Seams or Joints- Corrugated Metal, Concrete, Plastic Pipe, and Masonry Culverts

Code	Category	Description
9	Excellent	Straight line between sections.
8	Very Good	No settlement or misalignment; Tight with no apparent defects.
7	Good	Minor misalignment at joints; offsets less than ½ inch. Possible minor infiltration of fills no settlement. Minor distress to pipe material adjacent to joint. Shallow mortar deterioration at isolated locations.
6	Satisfactory	Minor backfill infiltration due to slight opening at joints; minor cracking or spalling at joints allowing exfiltration. Dislocated end section. Extensive areas of shallow deterioration; missing mortar at isolated locations; possible infiltration or exfiltration; minor cracking.
5	Fair	Joint open and allowing backfill to infiltrate; significant cracking, spalling, buckling of pipe material. Joint offset less than 3 inches. End sections dislocated about to drop off mortar generally deteriorated, loose or missing mortar at isolated locations; infiltration staining apparent.
4	Poor	Differential movement and separation of joints; significant infiltration or exfiltration at joints. Joint offset less than 4 inches. Voids seen in fill through offset joints. End sections dropped off at inlet. Mortar severely deteriorated, significant loss of mortar, significant infiltration or exfiltration between masonry units.
3	Serious	Significant openings, dislocated joints in several locations exposing fill material with joint offsets greater than 4 inches. Infiltration or exfiltration causing misalignment of pipe and settlement or depressions in roadway. Large voids seen in fill through offset joints. Extensive areas of missing mortar, infiltration or exfiltration causing misalignment of culvert and settlement or depressions in roadway.
2	Critical	Culvert not functioning due alignment problems throughout. Large voids seen in fill through offset joints.
1	Imminent Failure	Pipe partially collapsed or collapse is imminent.
0	Failed	Total failure of pipe.

4.5.5 Slab

Concrete slab should be inspected for cracks, scaling, leakage, deterioration, delaminations, spalling, efflorescence, honeycombs, pop-outs, wear, collision damage, abrasion, and reinforcing steel corrosion. Hammer and chain drags can be used to detect delaminated areas. Table 4.23 presents the slab rating (Item No. 5 on the CR-86 form).

Table 4.23: Slab

Code	Category	Description
9	Excellent	No signs of distress, no discoloration.
8	Very Good	Minor scaling (less than 1/8 inch deep over 5% of deck surface). Hairline cracking without rust staining or delaminations; no dampness, no leakage, no spalling. Isolated damage from construction.
7	Good	Hairline cracking w/ no single crack greater than 1/16 inch without rust staining parallel to the direction of traffic; light scaling on less than 10% of exposed area(less than 1/8 inch deep). Delaminated/ spalled area less than 1% of surface area (not including slab edges); isolated damage from construction or vehicle impact. <u>Note</u>: - Slab may have a single large crack (less than 3/16 inch) on bottom surface parallel to the direction traffic.
6	Satisfactory	Transverse cracks evident on bottom side (spacing 10' t0 20'), some could be leaking. Some spalling may be present (1%-10% of total deck area). Hairline map cracking combined with molted areas. Cracks (less than 1/8 inch) parallel to the traffic with minor efflorescence or minor amounts of leakage. Scaling on less than 20% of slab area. Additional delaminated/ spalled areas less than 10% of surface area (no including slab edges).
5	Fair	Map cracking. Cracks (less than 1/8 inch parallel to traffic, less than 1/16 inch transverse to traffic) with efflorescence and/or rust stain, leakage and molted areas. Scaling on less than 30% of exposed area (less than 3/16 inch deep). Spalled areas with exposed reinforcing less than 10%. Total delaminated/spalled areas less than 20% of surface area (not including slab edges).
4	Poor	Surface patches over at least 25% of deck area. Steel plates covering full depth holes. Map cracking with dark/damp areas and efflorescence over at least 30% of deck bottom. Several transverse cracks open more than 1/8 inch with efflorescence and rust staining. Spalling at numerous locations; extensive surface scaling greater than ½ inch. Included in distress areas (not including slab edges).
3	Serious	Same as "Poor" description except: Included in distress areas reinforcing steel bars have extensive section losses (greater than 20% of original diameter) for more than 5 adjacent bars.
2	Critical	Full depth holes. Cracking and white efflorescence. Total delaminated, spalled; map cracking and punky concrete areas are greater than 50% surface area. Reinforcing steel bars have extensive section losses (greater than 30% of original diameter) for more than 10 adjacent bars. Additional dark and damp areas over at least 50% of deck.
1	Imminent Failure	Slab partially collapsed or collapse is imminent.
0	Failed	Total failure of slab.

4.5.6 Abutment

Abutment is a sub-structural unit located at the ends of a bridge or slab culver. It provides end support to the culvert and retains the approach embankment. Wingwalls are also considered part of the abutment if they are integral with the abutment. Their function is only to retain the approach embankment not to provide support to the culvert. The wingwall is called independent and is not considered in the evaluation of abutment, if there is an expansion or construction joint between the abutment and the wingwall. The abutment should be inspected for vertical movement, lateral movement, rotational movement, material defects, foundation scouring, and drainage system malfunction. Tables 4.24 and 4.25 present masonry and concrete abutment rating, respectively (Item No. 7 on the CR-86 form).

Table 4.24: Abutment-Masonry

Code	Category	Description
9	Excellent	No signs of distress, Minor spalling of stone surface.
8	Very Good	Minor spalling of stone surface. Scaling on of stone surface less than 1/2 inch.
7	Good	Diagonal or vertical shear crack in isolated stones. Fracture of stone surface less than 2 inches.
6	Satisfactory	Diagonal or vertical shear crack through several courses of stone with some minor displacement. Spalls along edge of seat area.
5	Fair	Diagonal or vertical shear crack through several courses of stone with displacement. Displacement may be bulge or leaning stones. Total displacement is less than 1/4 of stone depth.
4	Poor	Settlement causing diagonal or vertical shear crack through several courses of stone with displacement. Total displacement is less than 1/3 of stone depth. Large fractures or erosion of stone surfaces less than 5 inches on several adjacent stones. Spalls on beam seats causing reduced bearing area.
3	Serious	Large unsound area; several stones are displaced or missing. Misalignment of mortar joints. Large fractures or erosion of stone surfaces greater than 5 inches. Spalls on beam seats causing reduced bearing area.
2	Critical	Numerous missing or displaced stones. Displacements greater than 1/3 of stone depth. Partially collapsed wingwall.
1	Imminent Failure	Partially collapsed abutment.
0	Failed	Total failure of abutment.

Table 4.25: Abutment-Concrete

Code	Category	Description
9	Excellent	No signs of distress, no discoloration.
8	Very Good	Minor scaling (less than 1/8 inch deep over 5% of concrete surface). Hairline cracking without rust staining or delaminations no dampness, no leakage, no spalling. Isolated damage from construction.
7	Good	Hairline cracking. No single crack greater than 1/16 inch without rust staining; light scaling on less than 10% or exposed area (less than 1/8 inch deep) delaminated/ spalled area less than 1 % of surface area.
6	Satisfactory	Hairline map cracking combined with molted areas. Horizontal and diagonal cracks (less than 1/8 inch) with minor efflorescence or minor amounts of leakage. Scaling on less than 20% of slab area (less than 1/4 inch deep). Spalled areas with exposed reinforcing less than 5% of slab area. Additional delaminated/ spalled areas less than 10% of surface area. Minor differential settlement.
5	Fair	Map cracking: Cracks (horizontal cracks less than 1/8 inch, diagonal cracks less than 1/16 inch) with efflorescence and/or rust stain, leakage and molted areas. Scaling on less than 30% of exposed area (less than 3/16 inch deep). Spalled areas with exposed reinforcing less than 10%. Total delaminated/spalled areas less than 20% of surface area. Moderate differential or rotational settlement.
4	Poor	Map cracking with dark/damp areas, effloresces and unsound concrete over 30% of abutment face. Several horizontal and diagonal cracks open more than 1/8 inch with efflorescence and rust staining. Spalling at numerous locations; extensive surface scaling greater than 1/2 inch. Included in distressed areas reinforcing steel bars have extensive section losses (greater than 10% of original diameter) for more than 4 adjacent bars. Total delaminated/spalled areas less than 25% of surface area. Severe differential or rotational settlement.
3	Serious	Map cracking with dark/damp areas and effloresces over at least 40% of abutment face. Several transverse cracks open more than1/4 inch with efflorescence and rust staining. Spalling at numerous locations; extensive surface scaling greater than 1/2 inch. Reinforcing steel bars have extensive section losses (greater than 10% of original diameter) for more than 4 adjacent bars. Total de1aminated/spalled areas less than 25% of surface area. Included in distressed areas reinforcing steel bars have extensive section losses (greater than 20% of original diameter) for more than 5 adjacent bars. Severe differential or rotational settlement.
2	Critical	Cracking and white efflorescence. Total delaminated, spalled, map cracking and unsound concrete areas are greater than 50% of surface area. Reinforcing steel bars have extensive section losses (greater than 30% of original diameter) for more than 10 adjacent bars. Included in distressed areas reinforcing steel bars. Extreme differential or rotational settlement.
1	Imminent Failure	Partially collapsed abutment.
0	Failed	Total failure of abutment.

4.5.7 Headwalls

Headwalls, endwalls, and wingwalls are used to retain the fill, resist erosion, improve hydraulic characteristics, resist uplifting, and resist horizontal forces that tend to separate sections of culvert. They are usually cast-in-place concrete but may also be constructed of timber, masonry, or other material including precast concrete. The inspector should check deterioration, settlement, vertical alignment, slides, scour, undercutting, any sign of failure, and all the problems listed under the abutment section. End treatment should also be inspected like any other structural component. Table 4.26 presents headwalls rating (Item No. 7 on the CR-86 form).

4.5.8 End Structure

End structures include catch basin, inlets, manholes, junction chambers, or any structure at the end of the culvert or storm sewer. Headwalls are not included under this item. These structures should be inspected for structural condition, connection with the conduit and their ability to convey water. Table 4.27 presents end structure rating (Item No. 8 on the CR-86 form).

4.6 CHANNEL RATING SYSTEMS

This section presents the channel rating which describes the conditions of the channel, riprap, and slope protection. Channel ratings include channel alignment, protection, culvert waterway blockage, and scouring.

Table 4.26: Headwall

Code	Category	Description
9	Excellent	No signs of distress, no discoloration.
8	Very Good	Minor scaling (less than 1/8 inch deep over 5% of concrete surface). Hairline cracking without rust staining or delaminations no dampness, no leakage, no spalling. Isolated damage from construction. Minor rotation of less than 1/2 inch per foot.
7	Good	Hairline cracking. No single crack greater than 1/16 inch. No rust staining; Light scaling on less than 10% of exposed area (less than 1/8 inch deep); Delaminated/Spalled area less than 1 % of surface area. Minor rotation of less than 1 inch per foot.
6	Satisfactory	Hairline map cracking combined with molted areas. Cracks (horizontal cracks less than 1/8 inch, diagonal cracks less than 1/16 inch) with minor efflorescence or minor amounts of leakage. Scaling on less than 20% of slab area (less than 1/4 inch deep). Spalled areas with exposed reinforcing less than 5% of slab area. Additional delaminated/spalled areas less than 10% of surface area. Minor differential settlement. Barrel pulling away from headwall (less than 1/2 inch gap).
5	Fair	Map cracking. Horizontal and diagonal cracks less than 1/8 inch with efflorescence and/or rust stain, leakage and molted areas. Scaling on less than 30% of exposed area (less than 3/16 inch deep). Spalled areas with exposed reinforcing less than 10%. Total delaminated/spalled areas less than 20% of surface area. Differential or rotational settlement. Barrel pulling away from headwall (less than 1 inch gap).
4	Poor	Map cracking with dark/damp areas, effloresces and unsound concrete over 30% of wall face. Several horizontal and diagonal cracks open more than 1/8 inch with efflorescence and rust staining. Spalling at numerous locations; extensive surface scaling greater than 1/2 inch. Included in distressed areas reinforcing steel bars have extensive section losses (greater than 10% of original diameter) for more than 4 adjacent bars. Total delaminated/spalled areas less than 25% of surface area. Severe differential or rotational settlement. Barrel pulling a way from headwall (less than 1 inch gap).
3	Serious	Map cracking with dark/damp areas and effloresces over at least 40% of wall face. Several transverse cracks open more than ¼ inch with efflorescence and rust staining. Spalling at numerous locations; extensive surface scaling greater than 1/2inch. Reinforcing steel bars have extensive section losses (greater than 10% of original diameter) for more than 4 adjacent bars. Total delaminated/spalled areas less than 25% of surface area. Included in distressed areas reinforcing steel bars have extensive section losses (greater than 20% of original diameter) for more than 5 adjacent bars. Severe differential or rotational settlement. (Rotation of less than 4 inches per foot).
2	Critical	Cracking and white efflorescence. Total delaminated, spalled, map cracking and unsound concrete areas are greater than 50% of surface area. Reinforcing steel bars have extensive section losses (greater than 30% of original diameter) for more than 10 adjacent bars. Included in distressed areas reinforcing steel bars.
1	Imminent Failure	Partially collapsed headwall.
0	Failed	Total failure of headwall.

Table 4.27: End Structure

Code	Category	Description
9	Excellent	No deterioration, like new condition.
8	Very Good	Minor scaling (less than 1/8 inch deep over 5% of concrete surface). Hairline cracking without rust staining or delaminations no dampness, no leakage, no spalling.
7	Good	Hairline cracking. No single crack greater than 1/16 inch. No rust staining; Light scaling on less than 10% of exposed area (less than 1/8 inch deep); delaminated/spalled area less than 1% of surface area. Grate or casting less than 1/4 inch off from proper grade. Minor amount of debris in basin (less than one inch).
6	Satisfactory	Hairline map cracking combined with molted areas. Cracks (horizontal cracks less than 1/8 inch, diagonal cracks less than 1/16 inch) with minor efflorescence. Spalled areas with exposed reinforcing less than 5% of slab area. Deterioration of small amount of mortar between masonry units (less than 20 percent). Moisture on walls from seepage around cracks or joints. Crack between barrel and structure wall (less than 1/4 inch gap with no infiltration of backfill material). Grate or casting less than 1/2 inch off from proper grade in traffic area. Minor amount of debris in basin (less than two inches).
5	Fair	Map cracking. Horizontal and diagonal cracks less than 1/8 inch with efflorescence and/or rust stain, and molted areas. Scaling on less than 30% of exposed area (less than 3/16 inch deep). Spalled areas with exposed reinforcing less than 10%. Total delaminated/spalled areas less than 20% of surface area. Deterioration of mortar between masonry units (less than 20 percent). Leakage around cracks or joints. Crack between barrel and structure wall (less than 1/2 inch gap with no infiltration of backfill material). Grate or casting less than 3/4 inch off from proper grade in traffic area. Debris in basin (less than four inches).
4	Poor	Map cracking with dark/damp areas, effloresces and unsound concrete over 30% of wall face. Several horizontal and diagonal cracks open more than 1/8 inch with efflorescence and rust staining. Spalling at numerous locations; extensive surface scaling greater than 1/2 inch. Deterioration of mortar between masonry units (less than 50 percent). Water trickling in through cracks or joints. Crack between barrel and structure wall (up to 3/4 inch gap with infiltration of backfill material). Grate or casting less than 1 inch off from proper grade in traffic area. Debris in basin (blocking up to half of capacity).
3	Serious	Map cracking with dark/damp areas and effloresces over at least 40% of wall face. Several transverse cracks open more than ¼ inch with efflorescence and rust staining. Spalling at numerous locations; extensive surface scaling greater than 1/2 inch. Deterioration of mortar between masonry units (more than 50 percent). Masonry units shifted or missing. Water running in through cracks or joints. Crack between barrel and structure wall (up to 1 inch gap with infiltration of backfill material). Grate or casting more than 1 inch off from proper grade in traffic area. Debris in basin (blocking more than half of capacity).
2	Critical	Cracking and white efflorescence. Total delaminated, spalled; map cracking and unsound concrete areas are greater than 50% of surface area. Masonry units missing and wall partially caved in. Barrel separated from structure wall. Grate or casting more than 2 inch off from proper grade or crushed or broken in traffic area. Debris in basin and conduit not visible.
1	Imminent Failure	Partially collapsed structure.
0	Failed	Total failure of structure .

4.6.1 Channel Alignment

The channel has to be aligned with the stream to flow through the center of the structure. The culvert may have more than one channel flowing to the inlet such as ditches alongside the roadway. Channel alignment rating should be governed by the worst case. The rating should not be low if the alignment was designated to be at a severe angle. Table 4.28 presents channel alignment rating (Item No. 9 on the CR-86 form).

Table 4.28: Channel Alignment

Code	Category	Description
9	Excellent	Channel is flowing through culvert causing no adverse conditions to channel protection or culvert.
8	Very Good	Channel has straight alignment for more than 100 feet upstream. Flow hits protective materials placed to protect culvert material.
7	Good	Silt and gravel buildup restricts half of the channel; Tree or bush growing in the channel.
6	Satisfactory	Flows through lout of 2 pipes; Flows along one abut. Doesn't flow under center of the culvert; minor curve (20^o-40^o angle); Deposits causing channel to split into 2 or more small channels. Minor streambed movement evident.
5	Fair	Flow hits outside headwall into unprotected embankment. Stream has meandered or has deposited sediment diverting flow causing erosion to embankment (Flow angle between 40°-50°) Trees and brushes restrict the channel.
4	Poor	Flows into or along wall to expose footing. Stream has meandered or has deposited sediment diverting flow causing erosion to embankment(Flow angle between 50°-70°) Flow enters pipe by other means than designed opening.
3	Serious	80° -90° turns at the bridge causing erosion behind wingwall. Loss of embankment material. Erosion to embankment encroaching on roadway. Lateral movement has changed the waterway to now threaten the culvert and /or approach roadway.
2	Critical	Flow is piping around culvert. Erosion to embankment impacting roadway surface. The water way has changed to the extent the bridge is near a state of collapse.
1	Imminent Failure	No flow enters culvert. All of the flow pipes around culvert barrel. Bridge closed because of channel failure.
0	Failed	Total failure of pipe.

4.6.2 Channel Protection

This item represents the method used to protect the bridge and channel banks from scouring and other degradation caused by stream actions. Table 4.29 presents channel protection rating (Item No. 10 on the CR-86 form).

Table 4.29: Channel Protection

Code	Category	Description
9	Excellent	Embankment protection are not required or are in a stable condition.
8	Very Good	No noteworthy deficiencies, which affect the condition of the channel protection 100 feet upstream. Banks are protected or well vegetated.
7	Good	Channel bank(s) is beginning to slump. Embankment protection has minor damage. Bank protection is in need of minor repairs.
6	Satisfactory	Riprap starting to washed away. Minor erosion. Cracked concrete channel protection at inlet of a culvert.
5	Fair	Broken up concrete channel protection at inlet of a culvert. Bank protection is being eroded.
4	Poor	Channel protection is severely undermined; Stone is completely washed away; Major erosion; Failed concrete channel protection at inlet of a culvert. Bank or embankment protection is severely undermined.
3	Serious	Channel protection has failed; channel has moved to where the bridge and approach roadway are threatened.
2	Critical	Channel protection has failed; channel flow is causing scour effects.
1	Imminent Failure	Culvert closed because of channel failure.
0	Failed	Total failure of pipe.

4.6.3 Culvert Waterway Blockage

Waterway blockage involves checking for indications of an inadequate opening. Contraction scour and stream bed degradation can be increased due to inadequate waterway areas in the culvert barrel. Geometry of barrel, amount of debris, and the adequacy of freeboard should be considered in determining waterway adequacy. In rating waterway blockage, the inspector should check for scour of the stream bed, banks, formation of sandbars, or debris, which could change flow direction. Table 4.30 presents culvert waterway blockage rating (Item No. 11 on the CR-86 form).

Table 4.30: Waterway Blockage

Code	Category	Description
9	Excellent	No blockage or as designed condition.
8	Very Good	Minor amounts of sediment build-up with no appreciable loss of opening.
7	Good	Culvert waterway blockage is less than 5% of the cross sectional area of the opening. Banks and/or channel have minor amounts of drift.
6	Satisfactory	Culvert waterway blockage is less than 10% of the cross sectional area of the opening. Sediment buildup causing flow thru one of 2 pipes; Silt and Gravel buildup restricts half of the channel; Tree or bush growing in the channel; Fence placed at inlet or outlet; Rock dams in culvert.
5	Fair	Culvert waterway blockage is less than 30%. Tree or bush growing in the channel; Fence placed at inlet or outlet; Rock dams in culvert. Trees and brush restrict the channel.
4	Poor	Culvert waterway blockage is less than 40% Occasional overtopping of roadway. Large deposits of debris are in the waterway.
3	Serious	Culvert waterway blockage is less than 80%. Overtopping of roadway with significant traffic delays.
2	Critical	Culvert waterway blockage is approximately 80%.Frequent overtopping of roadway with significant traffic delays.
1	Imminent Failure	Culvert waterway completely blocked and causing water to pool. Road closed because of channel failure.
0	Failed	Total failure of pipe.

4.6.4 Scour

Scour is the process of stream bed or bank area removal by stream flow. The inspector should indicate locations and extent of any undercutting around the ends of the culvert. Scouring depth should be measured. Piping can lead to unsupported culvert end. If not repaired in time, piping can cause cantilevered end portions of the culvert to bend down and restrict stream flow entering the culvert. The inspector should check for scouring evidence or undermining around footings at the inlet and outlet of the culvert. Table 4.31 presents culvert scour rating (Item No. 12 on the CR-86 form).

Table 4.31: Scour

Code	Category	Description
9	Excellent	No evidence of scour at either inlet or outlet of culvert.
8	Very Good	Minor scour holes developing at inlet or outlet. Scour protection placed.
7	Good	Minor scour holes developing at inlet or outlet. Top of footings is exposed. Probing indicates soft material in scour hole.
6	Satisfactory	Minor scour holes developing at inlet or outlet (1' or less deep). Footings along the side are exposed (less than 6 inches). Damage to scour counter measures. Probing indicates soft material in scour hole
5	Fair	Minor scour holes developing at inlet or outlet (2' or less deep). Footings along the side are exposed (less than 12 inches). Damage to scour counter measures. Probing indicates soft material in scour hole.
4	Poor	Significant scour holes developing at inlet or outlet (less than 3' deep). Does not appear to be undermining cutoff walls or headwalls. Bottom of footing is exposed. Major stream erosion behind headwall that threatens to undermine culvert.
3	Serious	Major scour holes at inlet or outlet (3' or deeper) undermining cutoff walls or headwalls. Footing is undermined.
2	Critical	Streambed degradation causing severe settlement.
1	Imminent Failure	Culvert closed because of channel failure.
0	Failed	Total failure of culvert because of channel failure.

4.7 APPROACHES RATING SYSTEMS

Approaches rating systems include pavement, guardrail, and embankment. The approach roadway and embankment should be inspected for alignment, adequate shoulder profile, and safety features. The approach pavement and embankment should be inspected for sag in roadway or guardrail, cracks in pavement, pavement patches or evidence that roadway has settled, and erosion or failure of side slopes. Approach roadways should be examined for sudden dips, cracks, and sag in the pavement. These usually indicate excessive deflection of the culvert or inadequate compaction of the backfill material. The approach guardrail should be inspected for sag in the alignment that may indicate settlement or embankment slips, integrity of posts, and condition of the rail panels. Approach embankment should be inspected for indication of settlement, bulging, and erosion from stream scour or saturation from entrapped water due to poor drainage. Embankment around the culvert entrance and exit should be inspected for slope failures, and debris should be check at the inlet and outlet. Tables 4.32, 4.33, and 4.34 present pavement, embankment, and guardrail ratings, respectively (Item Nos.13, 14 and 15 on the CR-86 form).

Table 4.32: Pavement

Code	Category	Description
9	Excellent	No noticeable defects.
8	Very Good	Hairline cracks in pavement. Minor scaling.
7	Good	Minor problems. Very small potholes, no settlement.
6	Satisfactory	Minor pavement deterioration, minor potholes, cracking or miner settlement.
5	Fair	Minor cracking, spalling. Moderate potholes, cracking, with settlement and misalignment.
4	Poor	Broken pavement with settlement and misalignment.
3	Serious	Major potholes and settlement. Repairs required immediately.
2	Critical	Significant pavement settlement/ cracking. Embankment washed out next to pavement.
1	Imminent Failure	Road closed. Impending pavement and / or embankment failure.
0	Failed	Road closed. Embankment and/ or pavement failed, impassible.

Table 4.33: Embankment

Code	Category	Description
9	Excellent	No noteworthy deficiencies which affect the condition of the embankment up to 1 00 feet away from the culvert.
8	Very Good	Minor rutting from drainage. Vegetation intact.
7	Good	Moderate rutting from drainage. Minor amount of bare soil exposed.
6	Satisfactory	Minor erosion caused by drainage.
5	Fair	Erosion caused by drainage or channel; Evidence of foundation settlement; Erosion to embankment impacting guardrail performance or encroaching on shoulder.
4	Poor	Major erosion caused by drainage or channel; Evidence of foundation settlement; Erosion to embankment impacting guardrail performance or encroaching on shoulder.
3	Serious	Shoulder eroded away. Guardrail post anchor undermined greater than 3 posts in a row.
2	Critical	A lane of traffic is closed due to embankment failure; Several guardrail posts are hanging due to major channel erosion.
1	Imminent Failure	Embankment failure could allow loss of culvert.
0	Failed	Embankment failed. Road closed.

Table 4.34: Guardrail

Code	Category	Description
9	Excellent	Guardrail is free from deficiencies. Minor discoloration.
8	Very Good	No noteworthy deficiencies, which affect the condition of the guardrail 100 feet from the end of the culvert.
7	Good	Minor deficiencies, which affect the condition of the guardrail 100 feet from the end of the culvert. Misalignment, of one or two guardrail posts.
6	Satisfactory	Minor collision damage; minor decay of posts; Guardrail is noticeably higher or lower than the standard 27 inches; Guardrail panels are very rusty; Several blockouts are missing. Misalignment of up to 3 posts in a row.
5	Fair	Major collision damage; 20% loss of section of posts due to decay; Several guardrail panels are not attached to posts. Installation of guardrail end assembly. Misalignment of up to 5 posts in a row.
4	Poor	Collision damage; 30% loss of section of posts due to decay; Several guardrail panels are not attached to posts. Poor installation of guardrail end assembly. Misalignment of up to 6 posts in a row.
3	Serious	Major collision damage; 50% loss of section of posts due to decay; Several guardrail panels are not attached to posts. Poor installation of guardrail end assembly. Misalignment of more than 6 posts in a row.
2	Critical	Guardrail is no longer functioning; Major decay of post (90%).
1	Imminent Failure	Guardrail partially collapsed.
0	Failed	Total failure guardrail.

4.8 LEVEL OF INSPECTION

Table 4.35 provides the code that can be used to specify the level of inspection utilized during the inspection procedure (Item No.16 on the CR-86 form).

Table 4.35: Level of Inspection

Code	Description
X	Inspection from culvert ends (no entry)
M	Manned entry inspection
V	Video inspection

4.9 GENERAL APPRAISAL AND OPERATIONAL STATUS

This is a two-part item as shown on the CR-86 form. The first box codes the overall culvert condition. The second box codes the operational status of the culvert. General appraisal is based on the existing condition of the culvert as compared to the as built condition. The load carrying capacity is not used in evaluating condition items. Tables 4.36 and 4.37 show general appraisal and operational status codes, respectively.

Table 4.36: Culvert Appraisal

Code	Description
9	As built condition - minor problems.
8	Very good condition - no problems noted Good condition – some.
7	Good condition- some minor problem.
6	Satisfactory condition-structural elements show some deterioration.
5	Fair condition - all primary structural elements are sound, but may have minor section loss.
4	Poor condition - advanced section loss, deterioration, or spalling.
3	Serious condition - loss of section, deterioration, or spalling have seriously affected primary structural components.
2	Critical condition - advanced deterioration of primary structural elements. Culvert should be closed or closely monitored, until corrective action is taken.
1	"Imminent" failure condition - major deterioration or section loss present on structural components. Culvert is closed to traffic.
0	Failed condition - out of service - beyond corrective action.

Table 4.37: Operational Status of Culvert

Code	Description
A	Open, no restriction.
B	Open, posting recommended but not legally implemented (all signs not in place).
C	Under construction, half of the existing culvert is open to traffic (half-width construction)
D	Open, would be posted or closed except for temporary shoring, etc. to allow for unrestricted traffic.
E	Open; temporary structure in place to carry legal loads while original structure is closed and awaiting replacement or rehabilitation.
G	New structure not yet opens to traffic.
K	Culvert closed to all traffic.
P	Posted for load-carrying capacity restriction (may include other restrictions).
R	Posted for other than load-carrying capacity restriction (speed, number of vehicles on bridge, etc.).
X	Culvert closed for reasons other than condition or load-carrying capacity.

4.10 MAINTENANCE AND REPAIR

Table 4.38 provides a list of potential maintenance and repair items. Based on the field observations, the inspector should select all applicable items from the list and record them in the CR-86 form. The list should be used by the culvert inspection reviewer along with other notes from the inspection, and if necessary a field investigation, to determine which items should be scheduled for maintenance and repair activities.

Table 4.38: Maintenance and Repair

PGAC	Activity Title	Unit of Measure
6132	Repairing Curbs, Gutters, and Paved Ditches	Linear Feet
6134	Repairing Slips and Slides	Square Yards
6135	Ditch and Shoulder Relocation	Square Yards
6141	Cleaning and Reshaping Ditches	Linear Feet
6142	Cleaning Channels	Linear Feet
6143	Cleaning Drainage Structure	Each
6144	Repairing / Replacing Drainage Structure	Each
6145	Tiger Ditching	Linear Feet
6146	Underdrain Maintenance	Each
6164	Cleaning Channels/Removing Debris	Each Structure
6224	Seeding, Sodding, and Fertilizing	Square Yards
6232	Litter Pick Up	Bags
6233	Guardrail Repair	Linear Feet
6331	Berm Betterment	Square Yards
6335	Roadside Betterment	Each
6343	Culvert Betterment	Linear Feet
6344	Catch Basin Repair, Replacement	Each

CHAPTER 5: FIELD INSPECTION OF HIGHWAY CULVERTS

5.1 INTRODUCTION

Under Task 3 of the project, a total of sixty (60) highway culverts in Ohio were to be inspected according to the methodology presented in the ODOT Culvert Management Manual (2003), described in detail previously in Chapter 4, as well as a more comprehensive methodology to be developed by ORITE. The goals of the state-wide culvert inspection program were to:

- Identify common distresses for each major type of highway culverts in Ohio.
- Identify trends among the field data collected.
- Evaluate the overall effectiveness of the methodology presented in the ODOT Culvert Management Manual (2003).
- Identify areas in which the new ODOT methodology can be further improved.
- Formulate a comprehensive culvert risk assessment method based on the data gathered during the field inspection program and results of statistical analysis.
- Compile a library of high-resolution photographs for ODOT which can be used in culvert inspection training programs.

5.2 CULVERT SELECTION METHODOLOGY

A formal request was issued from the ODOT central office to each ODOT district office to supply an inventory list of highway culvert structures recommended for the field inspection phase of the current research project. No specific instructions accompanied the request, so the selection criteria were totally left up to each district.

Eight (8) district offices responded to the request, each providing a list of recommended culvert structures. Table 5.1 summarizes the breakdown of the culverts recommended by these district offices. Tables 5.2.(a) through (g) provide descriptions of the culvert structures for each of the responding ODOT district offices. District 1, located near the northwestern region of the state, supplied basic information for six (3 concrete, 3 metal) culvert structures that were scheduled to be either repaired or replaced by 2006. District 2, located just north of District 1, recommended a total of 13 (10 concrete, 1 metal, 2 unknown) culvert structures. District 5, located in the central region (east of the Columbus area), identified a total of twelve (4 concrete, 7 metal, 1 thermoplastic) culvert structures. District 6, located just west of District 5, submitted six (3 concrete, 1 metal, 1 wooden, 1 unknown) culvert structures. District 8, located in the southwestern corner of the state, recommended four (3 concrete, 1 metal) culvert structures. District 9, located in the south-central region, provided information on eleven (4 concrete, 5 metal, 1 sandstone, 1 unknown) culvert structures. District 10, located in the southeastern region of the state, submitted the longest list of culvert structures, consisting of 52 (25 concrete, 24 metal, and 3 other) culverts. District 12, located near the northeastern corner of the state, identified four (1 concrete, 2 metal, 1 thermoplastic) culvert structures. The majority of these District 12 culverts were under interstate highways and involved twin or triplet culvert structures.

Table 5.1: Type and Number of Highway Culverts Recommended by Districts

Dist. No.	Office Location	No. of Culverts by Type:								
		Concrete:				CMP		Plastic		Other & Unknown
		Box	Pipe	Arch	Slab	Pipe	Arch	H	P	
1	Lima	0	1	0	2	2	1	0	0	0
2	Bowling Green	6	1	0	3	0	1	0	0	2
5	Jacksontown	2	2	0	0	7	0	1	0	0
6	Delaware	3	0	0	0	1	0	0	0	2
8	Lebanon	0	1	0	2	0	1	0	0	0
9	Chillicothe	1	0	2	1	3	2	0	0	2
10	Marietta	21	4	0	0	12	12	0	0	3
12	Garfield Heights	0	3	0	0	3	0	3	0	0
TOTAL = 113		33	12	2	8	28	17	4	0	9

[Notes] - Other types included culverts made of brick, timber, sandstone, and clay.
- Under Plastic, H = HDPE & P = PVC.

Table 5.2.(a): Culvert Structures Recommended by ODOT District 1

Culvert I.D.	Type	Size	Year	Length (ft.)	Cover (ft.)
WYA-103-1.06	Concrete, Slab	5’-0” Span	1955	NA	NA
PUT-189-10.5	Concrete, Slab	9’-0” Span	1956	NA	NA
PUT-15-14.78	CMP	8’-0” Dia.	1959	NA	NA
PAU-66-2.44	CMP, Twins	4’-6” & 4’-6” Dia.	1955	NA	NA
HAN-224-6.84	Concrete, Pipe	6’-0” Dia.	1956	NA	NA
DEF-18-20.6	Metal, Pipe-Arch	3’-8” Span x 6’-0” Rise	1941	NA	NA

[Note] “NA” = Not Available; 1’ = 0.31 m; 1” = 25 mm.

Table 5.2.(b): Culvert Structures Recommended by ODOT District 2

Culvert I.D.	Type	Size	Year	Length (ft.)	Cover (ft.)
FUL-20-2.14	Concrete, Ellipse	4’-2” Span	NA	70	NA
FUL-20-0.56	Unknown	2’-0” Dia.	NA	45	NA
FUL-30-1.59	Concrete, Box	5’-0” Span x 3’-4” Rise	NA	32	NA
FUL-20A-9.70	Metal, Pipe-Arch	10’-0” Span x 6’-0” Rise	NA	80	NA
HEN-65-6.51	Concrete, Box	8’-0” Span x 5’-0” Rise	NA	NA	NA
HEN-65-8.86	Concrete, Box	6’-0” Span x 5’-0” Rise	NA	NA	NA
SAN-635-1.40	Concrete, Box	8’-0” Span x 8’-0” Rise	NA	NA	NA
SAN-6-20.91	Concrete, Box	8’-0” Span x 8’-0” Rise	NA	NA	NA
SEN-635-1.40	Unknown	6’-0”	NA	50	NA
WOO-199-22.2	Concrete, Slab	8’-0” Span	NA	NA	NA
WOO-199-25.1	Concrete, Box	5’-0” Span	NA	NA	NA
WOO-65-0.69	Concrete, Slab	8’-0” Span	NA	NA	NA
WOO-65-13.43	Concrete, Slab	4’-0” Span	NA	NA	NA

[Note] “NA” = Not Available; 1’ = 0.31 m; 1” = 25 mm.

Table 5.2.(c): Culvert Structures Recommended by ODOT District 5

Culvert I.D.	Type	Size	Year	Length (ft.)	Cover (ft.)
MUS-93-1.76	CMP	8'-0" Dia.	NA	360	NA
LIC-70-13.52	Concrete, Pipe	6'-0" Dia.	NA	285	15
GUE-70-6.59	CMP	3'-6" Dia.	NA	568	40
GUE-70-8.94	CMP	5'-0" Dia.	NA	366	25
GUE-77-7.85R	CMP	6'-0" Dia.	NA	360	40
GUE-77-14.72	CMP	8'-0" Dia.	NA	342	40
LIC-16-13.66	CMP	6'-4" Dia.	NA	164	NA
KNO-95-0.08	CMP	4'-0" Dia.	NA	60	5
GUE-821-3.03	Concrete, Box	5'-0" Span x 4'-0" Rise	NA	34	5
COS-93-11.54	Concrete, Box	7'-0" Span x 5'-0" Rise	NA	50	NA
LIC-70-13.52	Concrete, Pipe	6'-0" Dia.	NA	285	15
PER-13-11.14	Plastic (HDPE)	3'-6" Dia.	NA	60	3

[Note] "NA" = Not Available; 1' = 0.31 m; 1" = 25 mm.

Table 5.2.(d): Culvert Structures Recommended by ODOT District 6

Culvert I.D.	Type	Size	Year	Length (ft.)	Cover (ft.)
MAD-29-8.80	CMP	7'-0" Dia.	NA	NA	NA
MAD-29-11.37	Concrete, Box	4'-0" Span	NA	NA	NA
MAD-142-4.30	Concrete, Box	4'-0" Span x 6'-0" Rise	NA	NA	NA
UNI-4-25.04	Wood, Deck	6'-0" Span	NA	NA	NA
FAY-753-2.09	Concrete, Box	NA	NA	NA	NA
PIC-22-?	Unknown	NA	NA	NA	NA

[Note] "NA" = Not Available; 1' = 0.31 m; 1" = 25 mm.

Table 5.2.(e): Culvert Structures Recommended by ODOT District 8

Culvert I.D.	Type	Size	Year	Length (ft.)	Cover (ft.)
BUT-126-2.58	Concrete, Slab	8'-6" Span	NA	52.5	1.5
CLI-28-7.84	Concrete, Slab	8'-0" Span	1932	34	1.5
CLI-124-0.03	Metal, Pipe-Arch	9'-6" Span x 6'-5" Rise	1956	106	1.75
GRE-380-5.03	Concrete, Pipe	2'-6" Dia.	1941	45	2.1

[Note] "NA" = Not Available; 1' = 0.31 m; 1" = 25 mm.

Table 5.2.(f): Culvert Structures Recommended by ODOT District 9

Culvert I.D.	Type	Size	Year	Length (ft.)	Cover (ft.)
HIG-50-23.93	Concrete, Arch	6'-8" Span x 3'-0" Rise	NA	NA	NA
HIG-134-16.34	Sandstone, Arch	NA	NA	NA	NA
HIG-50-19.82	CMP	6'-0" Dia.	NA	NA	NA
ADA-348-10.22	Unknown	3'-6" Dia. ; Twins	NA	NA	NA
ADA-125-19.02	Concrete, Arch	NA	NA	NA	NA
ADA-247-11.87	Metal, Pipe-Arch	5'-4" Span x 3'-6" Rise	NA	NA	NA
BRO-52-16.16	Concrete, Box	NA	NA	NA	NA
PIK-32-15.96	CMP	7'-0" Dia.	NA	NA	NA
PIK-772-0.98	CMP	3'-0" Dia.	NA	NA	NA
JAC-93-21.04	Concrete, Slab	8'-0" Span	NA	NA	NA
JAC-124-17.12	Metal, Pipe-Arch	7'-3" Span x 5'-3" Rise	NA	NA	NA

[Note] "NA" = Not Available; 1' = 0.31 m; 1" = 25 mm.

Table 5.2.(g): Culvert Structures Recommended by ODOT District 10

Culvert I.D.	Type	Size	Year	Length (ft.)	Cover (ft.)
GAL-7-12.54	CMP	3'-0" Dia.	1930	84	9
GAL-141-21.55	Concrete, Pipe	NA	NA	1150	3
HOC-328-4.93	Clay, Pipe	3'-0" Dia.	1966	44	3
WAS-60-4.84	CMP	8'-0" Dia.	1961	150	21
GAL-7-0.22	CMP	2'-6" Dia.	1939	104	14
HOC-93-1.1	Concrete, Box	6'-0" Span x 4'-0" Rise	1968	81	2
ATH-78-4.08	CMP	1-3" Dia.	1938	202	28
ATH-78-4.17	CMP	1'-6" Dia.	1938	108	17
VIN-93-11.17	CMP	1-3" Dia.	1958	122	11
HOC-78-1.05	Concrete, Box	6'-0" Span x 4'-0" Rise	1924	39	1
GAL-7-21.3	CMP	2'-6" Dia.	1940	108	11
ATH-278-0.25	Metal, Pipe-Arch	6'-11" Span x 4'-0" Rise	NA	40	NA
ATH-690-0.68	Concrete, Pipe	1'-6" Dia.	1939	70	16
GAL-7-29.86	Concrete, Pipe	3'-0" Dia.	1936	139	15
HOC-56-2.83	CMP	3'-0" Dia.; Twin	NA	90	NA
HOC-56-15.26	Metal, Pipe-Arch	8'-2" Span x 6'-9" Rise	1948	32	2
HOC-56-17.57	Metal, Pipe-Arch	6'-4" Span x 4'-9" Rise	1951	56	1
HOC-78-0.72	Concrete, Box	6'-0" Span x 3'-0" Rise	1924	30	1
HOC-216-2.77	Concrete, Box	9'-0" Span x 7'-0" Rise	1961	32	NA
HOC-216-3.25	Concrete, Box	4'-0" Span x 3'-0" Rise	NA	43	2
HOC-216-3.43	Concrete, Box	5'-0" Span x 3'-0" Rise	1932	56	2
HOC-595-1.35	Metal, Pipe-Arch	3'-6" Span x 2-3" Rise ; Twin	1961	40	2
HOC-595-2.85	Metal, Pipe-Arch	7'-8" Span x 5'-5" Rise	1951	52	1
HOC-595-4.57	Metal, Pipe-Arch	7'-3" Span x 5'-3" Rise	1961	60	2
HOC-664-6.88	Metal, Pipe-Arch	6'-1" Span x 4'-7" Rise	NA	104	3
HOC-664-11.87	Metal, Pipe-Arch	9'-6" Span x 6'-5" Rise	1959	70	4
HOC-664-17.16	Metal, Pipe-Arch	8'-7" Span x 5'-11" Rise	1959	66	1
HOC-664-22.4	CMP	7'-0" Dia.	1956	100	12
MEG-124-24.65	Sandstone, Arch	8'-0" Span x 8'-6" Rise	1900	73	16
MEG-124-30.17	Concrete, Box	3'-0" Span x 4'-0" Rise	NA	50	3
MEG-338-16.42	Concrete, Box	4'-0" Span x 4'-0" Rise	NA	74	8
MEG-681-7.94	CMP	6'-0" Dia.	1962	74	6
MEG-681-13.96	Metal, Pipe-Arch	7'-3" Span x 5'-3" Rise	1960	72	4
MEG-681-18.86	Metal, Pipe-Arch	6'-1" Span x 4'-7" Rise	1953	40	2
MRG-37-1.57	Concrete, Box	2'-6" Span x 2'-6" Rise	1923	31	2
MRG-37-2.66	Concrete, Box	2'-6" Span x 2'-6" Rise	1922	31	2
MRG-37-7.43	Concrete, Box	3'-0" Span x 2'-6" Rise	1930	29	4
MRG-37-7.56	Concrete, Box	4'-0" Span x 3'-0" Rise	1930	54	4
MRG-37-7.68	Concrete, Box	2'-0" Span x 2'-0" Rise	1930	44	6
MRG-60-19.95	Concrete, Box	4'-0" Span x 6'-0" Rise	1930	50	3
MRG-78-8.56	Concrete, Box	6'-0" Span x 4'-0" Rise	1928	68	5
MRG-78-11.34	Concrete, Box	8'-0" Span x 6'-0" Rise	1928	44	3
MRG-78-15.96	Concrete, Box	5'-0" Span x 3'-0" Rise	NA	52	5
MRG-78-24.40	Concrete, Box	4'-0" Span x 3'-0" Rise	1968	30	1
MRG-78-24.97	Concrete, Box	2'-6" Span x 2'-6" Rise	1968	42	4
MRG-377-5.06	Concrete, Box	5'-0" Span x 4'-0" Rise	1926	32	1
NOB-146-13.75	CMP	3'-0" Dia.	1955	40.5	1
VIN-50-15.41	Brick, Box	4'-0" Span x 4'-0" Rise	1920	22	2

[Note] "NA" = Not Available; 1' = 0.31 m; 1" = 25 mm.

Table 5.2.(g): Culvert Structures Recommended by ODOT District 10 – cont'd

Culvert I.D.	Type	Size	Year	Length (ft.)	Cover (ft.)
VIN-56-6.85	Concrete, Box	8'-0" Span x 6'-0" Rise	1928	57	6
VIN-328-4.37	Metal, Pipe-Arch	4'-10" Span x 3'-0" Rise	1954	37	1
WAS-50-0.20	Concrete, Pipe	2'-3" Dia.	1961	174	15
WAS-339-15.53	CMP	9'-0" Dia.	1959	92	8

[Note] "NA" = Not Available; 1' = 0.31 m; 1" = 25 mm.

Table 5.2.(h): Culvert Structures Recommended by ODOT District 12

Culvert I.D.	Type	Size	Year	Length (ft.)	Cover (ft.)
CUY-480-0.62 to 1.07	CMP, Triplet Pipes	3'-0", 3'-6", 4'-0" Dia.	1978	763, 837, 830	6
LAK-90-14.69	CMP	6'-0" Dia.	1959	1362	35 to 58
CUY-480-19.22	HDPE, Twin Pipes	4'-0" & 4'-6" Dia.	2002	2615, 955	8
CUY-77-11.45 to 12.72	Concrete, Triplet Pipes	2'-6", 2'-9", 3'-6" Dia.	1972	618, 125, 3439	5 to 16

[Note] "NA" = Not Available; 1' = 0.31 m; 1" = 25 mm.

With a general lack of thermoplastic pipe culverts in the initial pool, the ODOT main office personnel contacted a number of district hydraulic engineers and established a separate listing of thermoplastic pipe culverts recommended for Task 3 (shown in Table 5.3).

Table 5.3: Thermoplastic Pipe Culverts Recommended

District & Culvert I.D.		Type	Diam.	Year	Length (ft.)	Cover (ft.)
5	FAI-33b-446+92	HDPE, Honeycomb	5'-0"	2002	NA	13
5	FAI-33b-587+96	PVC	4'-0"	2002	NA	17
5	FAI-22-17+20	PVC	3'-0"	2002	NA	22
5	FAI-33b-Ramp G: 488+70	HDPE, Corrugated	2'-6"	2002	NA	25
5	FAI-33b-Ramp H: 482+35	HDPE, Corrugated	2'-6"	2002	NA	26
5	FAI-33b-Ramp J: 488+07	PVC	2'-6"	2002	NA	21
5	FAI-33b-S.R.1: 62+66.5	HDPE	3'-0"	2002	NA	NA
5	FAI-33b-S.R.18: 86+00	HDPE	3'-0"	2002	NA	NA
5	FAI-33b-S.R.18: 96+00	PVC	3'-0"	2002	NA	NA
5	PER-13-11.14	HDPE, Corrugated	3'-6"	2000	60	3
6	DEL-656-0.24	HDPE, Corrugated	2'-6"	NA	NA	5
6	DEL-656-0.36	HDPE, Corrugated	2'-6"	NA	NA	10
10	HOC-327-2.70	HDPE, Corrugated	3'-6"	2001	NA	1
10	NOB-145-3.59	HDPE, Corrugated	2'-0"	1981	NA	1.3

[Note] Diam. = Diameter; 33b = 33 Bypass; S.R.1 = Service Road 1; S.R.18 = Service Road 18.
1' = 0.31 m; 1" = 25 mm.

Once the lists of recommended culvert structures were received from the district offices, sixty structures were to be selected by the ORITE personnel in consultation with the ODOT for the field inspection phase. With the total number specified to be 60, the target number for each culvert material type was initially set at -- concrete culverts (25 structures), metal culverts (25 structures), and thermoplastic pipe culverts (10 structures).

While selecting the culvert structures from the district composite lists, culverts under interstate highways received priority. A decision was made not to inspect culverts that are less than 24 inches (0.61 m) in span, due to general difficulty in inspecting these small size culverts. Also, it was decided to exclude any culverts that are constructed from materials other than concrete, corrugated metal, or thermoplastics (ex. sandstone, timber, brick, …). This was because the majority of highway culverts in Ohio are made from concrete, corrugated metal, and thermoplastics. An effort was made in selecting the sixty culverts to reflect a variety of conditions for the following key characteristic parameters to produce relatively unbiased sample populations for the subsequent statistical analysis.

- Material type (concrete; metal; thermoplastic).
- Shape type (circular pipe; pipe-arch; box; ellipse; slab-on-top).
- Age (less than 30 years; 30 to 60 years; more than 60 years).
- Size classification – Diameter or Rise in (2' to 4'), (4' to 6'), and (≥ 6'); or Diameter or Rise in (0.61 to 1.22 m), (1.22 to 1.83 m), and (≥ 1.83 m).
- Ratio of (Soil Cover Height) divided by (Culvert Diameter or Rise).
- Classification of roadway (interstate; U.S. route; state route; …).

- Environmental conditions (abrasive & nonabrasive drainage flow; low-pH drainage flow).
- Types of Problem:
    - Metal (deflections; corrosion; stress cracks; alignment; settlement; seam problem; scouring).
    - Concrete (cracking; spalling; alignment; settlement; joint opening; scouring).
    - Plastic (excessive deflections; wall buckling; cracking; alignment; settlement; joint opening).

5.3 CHARACTERISTICS OF SELECTED CULVERTS

5.3.1 List of Culverts Selected and Inspected

The culvert structures selected for inspection are listed in Table 5.4. In most cases, the research team was able to locate the selected culvert and inspect it in detail in the field. In a few isolated instances in District 12, the team could not locate the selected culvert structure and had to find a comparable alternate structure in the same geographical area. The final list included six (3 concrete, 3 metal) from District 1, fourteen (2 concrete, 5 metal, 7 thermoplastic) from District 5, five (4 concrete, 1 metal) from District 6, four (3 concrete, 1 metal) from District 8, five (1 concrete, 4 metal) from District 9, twenty-two (10 concrete, 9 metal, 3 thermoplastic) from District 10, and four (2 concrete, 2 metal) from District 12. The total number of 60 consisted of 25 concrete culverts, 25 metal culverts, and 10 thermoplastic pipe culverts. Figures 5.1 through 5.3 show the locations of these culverts in the state for concrete, metal, and thermoplastic pipe culverts, respectively. In these figures, in some cases the red dot represents more than one culvert located in the area.

Table 5.4: List of Sixty Culverts Inspected

District	Culvert I.D.	Basic Description	Age	L	H
01	PUT-189-10.5	9'-0" Span Concrete Slab-on-Top	48	29	0.6
01	PAU-66-2.44	4'-6" Dia. Corrugated Metal Pipe	49	65	4.5
01	DEF-18-20.60	3'-8" x 6'-0" Metal Pipe-Arch	63	50	2.75
01	PUT-15-14.78	8'-0" Dia. Corrugated Metal Pipe	45	107	8
01	HAN-224-6.84	6'-0" Dia. Concrete Pipe	48	129	13.5
01	WYA-103-1.06	5'-0" Span Concrete Slab-on-Top	49	27	0.6
05	LIC-16-13.66	7'-0" Dia. Corrugated Metal Pipe	NA	164	17
05	LIC-70-13.52	6'-0" Dia. Concrete Pipe	40	285	15
05	GUE-70-8.94	5'-0" Dia. Corrugated Metal Pipe	40	366	35
05	MUS-93-1.76	8'-0" Dia. Corrugated Metal Pipe	43	360	64
05	GUE-77-7.85R	6'-0" Dia. Corrugated Metal Pipe	NA	300	40
05	PER-13-11.14	3'-6" Dia. HDPE Pipe	4	60	1.5
05	FAI-33b-Sta. 587+96	4'-0" Dia. PVC Pipe	2	173	14
05	FAI-22-Sta. 17+20	3'-0" Dia. PVC Pipe	2	104	22
05	FAI-33b-S. Rd. 18-Sta. 96+00	3'-0" Dia. PVC Pipe	2	59	2
05	FAI-33b-S. Rd. 18-Sta. 86+00	3'-0" Dia. HDPE Pipe	2	127	13
05	FAI-33b-Sta. 446+92	5'-0" Dia. HDPE Pipe	2	272	13
05	FAI-33b-Ramp J (Sta. 488+7)	2'-6" Dia. PVC Pipe	< 1	153	17
05	COS-93-11.54	7'-0" x 5'-0" Concrete Box	NA	50	3
05	KNO-95-0.08	4'-0" Dia. Corrugated Metal Pipe	NA	60	5
06	MAD-29-8.80	7'-0" Dia. Corrugated Metal Pipe	NA	50	2
06	MAD-29-11.37	4'-0" x 4'-0" Concrete Box	72	60	1
06	MAD-142-4.30	6'-0" x 4'-0" Concrete Box	81	43	2
06	FAY-753-2.09	7'-0" x 5'-8" Concrete Box	NA	41	2
06	PIK-335-5.18	14'-0" Span Concrete Slab-on-Top	NA	57	3
08	CLI-28-7.84	8'-0" Span Concrete Slab-on-Top	72	34	1
08	CLI-124-0.03	9'-6" x 6'-5" Metal Pipe-Arch	48	107	5.5
08	BUT-126-2.58	8'-6" x 5'-6" Concrete Box	40?	78	1.5
08	GRE-380-5.03	2'-6" Dia. Concrete Pipe	63	53	2.1
09	HIG-50-19.82	6'-0" Dia. Corrugated Metal Pipe	NA	59	5
09	JAC-124-17.12	7'-3" x 5'-3" Metal Pipe-Arch	NA	55	2.5
09	PIK-32-15.96	7'-0" Dia. Corrugated Metal Pipe	NA	391	16
09	HIG-124-25.75	6'-3" x 4'-0" Concrete H. Ellipse	NA	54	2.5
09	ADA-247-11.87	4'-0" Dia. Corrugated Metal Pipe	NA	39	1
10	HOC-595-2.85	7'-8" x 5'-5" Metal Pipe-Arch	53	52	1
10	HOC-216-1.99	9'-0" x 7'-0" Concrete Box	43	32	1
10	HOC-78-1.05	6'-0" x 4'-0" Concrete Box	80	39	1
10	HOC-664-17.16	8'-6" x 5'-9" Metal Pipe-Arch	45	66	1
10	HOC-664-22.40	7'-0" Dia. Corrugated Metal Pipe	48	99	12
10	GAL-7-21.30	2'-6" Dia. Corrugated Metal Pipe	64	108	10
10	MEI-681-7.94	5'-0" Dia. Corrugated Metal Pipe	42	74	6
10	MEI-681-13.96	7'-3" x 5'-4" Metal Pipe-Arch	44	72	3
10	HOC-595-4.57	7'-4" x 5'-3" Metal Pipe-Arch	43	66	1.5

[Note] L = Length (ft.); and H = Cover (ft.); 1' = 0.31 m; 1" = 25 mm.

Table 5.4: List of Sixty Culverts Inspected - cont'd

District	Culvert I.D.	Basic Description	Age	L	H
10	HOC-216-3.25	4'-0" x 3'-0" Concrete Box	72	43	3
10	HOC-216-3.43	5'-0" x 3'-0" Concrete Box	72	56	2
10	MRG-78-11.34	8'-0" x 6'-0" Concrete Box	76	44	4
10	MRG-78-24.97	2'-6" x 2'-6" Concrete Box	36	80	4
10	VIN-56-6.85	8'-0" x 6'-0" Concrete Box	76	57	4.5
10	MEI-124-30.17	4'-0" Dia. HDPE Pipe	NA	60	6
10	MEI-338-16.42	4'-0" x 4'-0" Concrete Box	76	74	8
10	WAS-339-15.25	6'-0" Dia. Corrugated Metal Pipe	45	82	6
10	WAS-60-4.84	8'-0" Dia. Corrugated Metal Pipe	43	150	21
10	ATH-278-0.25	7'-6" x 4'-10" Concrete H. Ellipse	2	48	1
10	HOC-327-2.70	3'-6" Dia. HDPE Pipe	3	40	1.5
10	NOB-145-3.59	2'-0" Dia. HDPE Pipe	23	41	1.3
10	MRG-60-19.95	4'-0" x 6'-0" Concrete Box	74	48	1
12	CUY-480-0.5	7'-0" Dia. Concrete Pipe	NA	224	3
12	LAK-90-14.0	15'-0" Dia. Corrugated Metal Pipe	45	420	40
12	LAK-90-4.2	10'-0" Dia. Corrugated Metal Pipe	45	922	60
12	CUY-422-15.2	4'-0" Dia. Concrete Pipe	NA	178	4

[Note] L = Length (ft.); and H = Cover (ft.); 1' = 0.31 m; 1" = 25 mm.

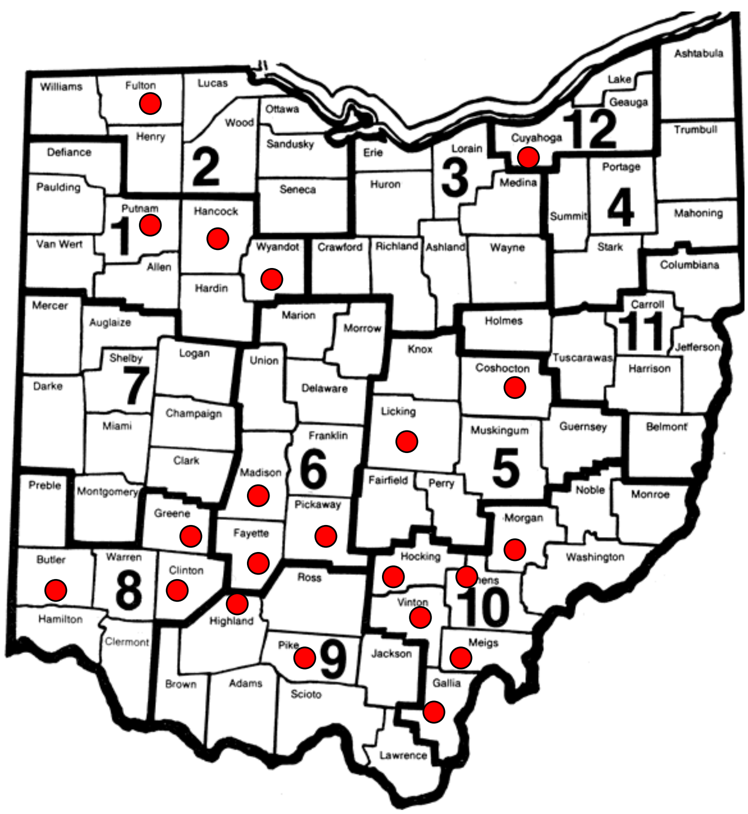


Figure 5.1: General Locations of Concrete Culverts Inspected

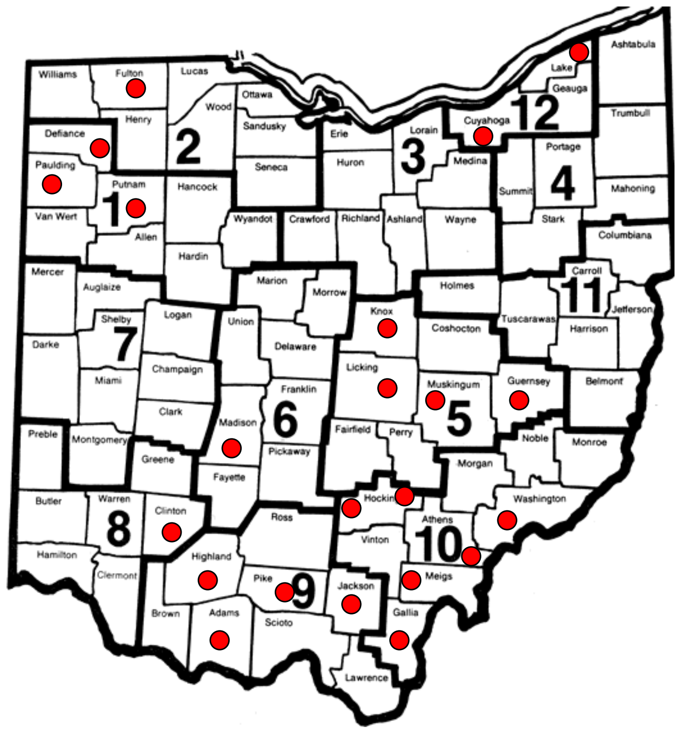


Figure 5.2: General Locations of Metal Culverts Inspected

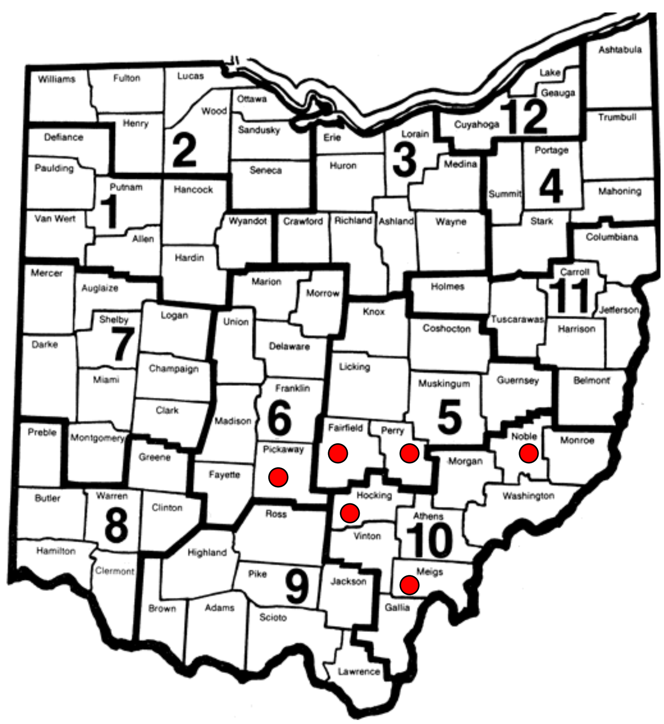


Figure 5.3: General Locations of Thermoplastic Pipe Culverts Inspected

5.3.2 Culvert Material and Shape Characterizations

Table 5.5 presents shape classifications for the concrete and metal culverts inspected and material classification for the thermoplastic pipes inspected. According to the table, percentage breakdowns of the concrete culvert shapes were 8% horizontal ellipse, 16% slab-on-top, 20% circular, and 56% box. The shapes of corrugated metal culverts were 28% pipe-arch and 72% circular. Forty percent (40%) and 60% of the thermoplastic pipes were PVC and corrugated HDPE pipes, respectively.

Table 5.5: Shape Classification of Selected Highway Culverts

(a) Concrete Culverts

Shape	Circular Pipe	Ellipse	Box	Slab-on-Top
Number	5	2	14	4

(b) Metal Culverts

Shape	Circular Pipe	Pipe-Arch
Number	18	7

(c) Thermoplastic Pipe Culverts

Shape	Circular (HDPE)	Circular (PVC)
Number	6	4

5.3.3 Culvert Age Characterization

Table 5.6 presents age classifications for the inspected culverts. According to the table, the age distribution among the concrete culverts was relatively uniform. The percentage breakdowns of the concrete culvert age were 32% 50 years or less, 24% 50 to 75 years, 20% more than 75 years, and 24% unknown. The ages of corrugated metal culverts were more narrowly scattered with 56% between 25 to 50 years, 12% 50 to 75 years, and 32% having unknown age. Only one thermoplastic pipe culvert had its age surpassing 20 years with the remainder less than 10 years.

Table 5.6: Age Classification of Selected Highway Culverts

(a) Concrete Culverts

Age (Years)	Age ≤ 25	25 < Age ≤ 50	50 < Age ≤ 75	Age > 75	Unknown
Number	1	7	6	5	6

(b) Metal Culverts

Age (Years)	Age ≤ 25	25 < Age ≤ 50	50 < Age ≤ 75	Age > 75	Unknown
Number	0	14	3	0	8

(c) Thermoplastic Pipe Culverts

Age (Years)	Age ≤ 10	10 < Age ≤ 20	20 < Age ≤ 30
Number	9	0	1

5.3.4 Culvert Span/Diameter Classifications

Table 5.7 presents a classification of the inspected culverts in terms of the span dimension. The span was less than or equal to 8 ft (2.44 m) for all but one of the concrete culverts and 60% had spans between 5 and 8 ft (1.52 and 2.44 m). The largest span among the concrete culverts was 14 ft (4.27 m), which was a slab-on-top structure (PIK-335-5.18). The span dimension of the metal culverts varied more widely between 2.5 and 10 ft (0.61 and 3.05 m). The diameter of the thermoplastic pipes fell mostly between 2 and 4 ft (0.61 and 1.22 m), with only one HDPE pipe (FAI-33b-Sta. 446+92) having a diameter of 5 ft (1.52 m).

Table 5.7: Span Dimension Classification of Selected Highway Culverts

(a) Concrete Culverts

Span (S)	2 ≤ S ≤ 5 ft.	5 < S ≤ 8 ft.	8 ft. < S
Number	9	15	1

(b) Metal Culverts

Span (S)	2 ≤ S ≤ 5 ft.	5 < S ≤ 8 ft.	8 ft. < S
Number	7	14	4

(c) Thermoplastic Pipe Culverts

Diameter (D)	2 ≤ D ≤ 3 ft.	3 < S ≤ 4 ft.	4 ft. < S
Number	5	4	1

[Note] 1 ft = 0.305 m.

5.3.5 Culvert Length Classifications

Table 5.8 presents a classification of the inspected culverts in terms of the overall length. According to the table, the length varied widely among each major culvert type, with those under shallow cover and 2-lane roadways having less than 50 ft (15.2 m) length and others under deep cover or under interstate highways having more than 200 ft (61.0 m). The skew angle obviously affected the overall length of the culverts. The longest concrete culvert structure was a 6-ft (1.8-m) diameter RCP identified as LIC-70-13.52 (length 285 ft or 86.9 m). Six metal culvert structures were longer than 200 ft (61.0 m). The longest metal culvert structure was a 15-ft (4.6-m) diameter CMP identified as LAK-90-4.2 (length 922 ft or 281.0 m). The longest thermoplastic pipe culvert was a 5-ft (1.5-m) diameter HDPE pipe identified as FAI-33b-Sta. 446+92 (length 272 ft or 82.9 m).

Table 5.9 classifies the concrete and thermoplastic pipe culverts in terms of the number of sections. The old cast-in-place structure made up 72% of all the concrete culverts. Four of the concrete culverts, most located under interstate highways, had more than twenty sections. The concrete culvert with the largest number of sections was LIC-70-13.52 with fifty-seven RCP sections joined together. Thermoplastic pipes under two-lane roads had only a few sections. The thermoplastic pipe with the most number of sections was FAI-33b-(Sta. 446+92) with a total of thirteen sections.

Table 5.8: Length Classification of Selected Highway Culverts

(a) Concrete Culverts

Length (L)	L ≤ 50 ft.	50 < L < 100 ft.	100 < L < 200 ft.	200 ft. < L
Number	12	9	2	2

(b) Metal Culverts

Length (L)	L ≤ 50 ft.	50 < L < 100 ft.	100 < L < 200 ft.	200 ft. < L
Number	3	11	5	6

(c) Thermoplastic Pipe Culverts

Length (L)	L ≤ 50 ft.	50 < L < 100 ft.	100 < L < 200 ft.	200 ft. < L
Number	2	3	4	1

[Note] 1 ft = 0.305 m.

Table 5.9: Culvert Classifications In Terms of Number of Sections

(a) Concrete Culverts

No. of Sections	1 (cast in-place)	2 to 10	11 to 20	> 20
Number	18	3	0	4

(b) Thermoplastic Pipe Culverts

No. of Sections	2 to 4	5 to 10	11 to 15	> 15
Number	4	4	2	0

5.3.6 Soil Cover Height Characterization

Variations in the cover thickness (installation depth) among the inspected culverts are summarized in Table 5.10. The majority (88%) of the concrete culverts had shallow covers of less than or equal to 5 ft (1.5 m). None of the concrete culverts were installed under more than 20 ft (6.1 m) of cover. On the contrary, 44% of the metal culverts were under shallow coverts. And, 24% of the metal culverts were installed at least 20 ft (6.1 m) deep. The maximum cover height for the metal culverts was 64 ft (19.5 m) found at the site of MUS-93-1.76. Most of the thermoplastic pipes were installed below 20 ft (6.1 m) of soil cover. The minimum cover height was 1.3 ft (0.4 m) at a 2-ft (0.61-m) diameter HDPE pipe NOB-145-3.59, and the maximum cover height of 22 ft (6.7 m) was found over a 3-ft (0.61-m) diameter PVC pipe FAI-22-Sta. 17+20.

Table 5.10: Soil Cover Classification of Selected Highway Culverts

(a) Concrete Culverts

Cover Thickness (H)	0' < H ≤ 5'	5' < H ≤ 10'	10' < H ≤ 20'	20' < H
Number	22	1	2	0

(b) Metal Culverts

Cover Thickness (H)	0 < H ≤ 5'	5 < H ≤ 10'	10' < H ≤ 20'	20' < H ≤ 30'	30' < H
Number	11	5	3	1	5

(c) Thermoplastic Pipe Culverts

Cover Thickness (H)	0' < H ≤ 5'	5' < H ≤ 10'	10' < H ≤ 20'	20' < H
Number	4	1	4	1

[Note] 1 ft = 0.305 m.

5.3.7 Traffic Load Characterization

Roadway and ADT classifications are presented in Tables 5.11 and 5.12. About 80% of the concrete and metal culverts were located on the state highways. None of the thermoplastic pipe culverts inspected served the interstate highways. One category "Others" mentioned for the thermoplastic pipes represented service roads and the exit ramp sections of a highway.

Examining the ADT data, 28% of the concrete culvert structures were under very small numbers (ADT less than 1,000) of traffic loading, while 12% of the concrete culverts were under large numbers (> 30,000) of traffic loading. The top three ADT counts existed at CUY-422-15.2 (ADT 73,580), CUY-480-0.5 (ADT 54,140), and LIC-70-13.52 (ADT 51,940). Among the metal culverts selected in the study, only 12% were under very small numbers (ADT less than 1,000) of traffic loading, while 12% were under large numbers (> 30,000) of traffic loading. The top three ADT counts existed at LAK-90-4.2 (ADT 67,850), LAK-90-14.0 (ADT 48,410), and GUE-70-8.94 (ADT 34,570). None of the thermoplastic pipe culverts selected for the study was subjected to large numbers of traffic loading. Six percent (60%) of the thermoplastic pipe culverts were installed at a major highway construction site in District 5 and were not yet subjected to any constant traffic loading.

Table 5.11: Roadway Classification of Selected Highway Culverts

(a) Concrete Culverts

Roadway Type	Interstate Highway	U.S. Highway	State Highway
Number	2	2	21

(b) Metal Culverts

Roadway Type	Interstate Highway	U.S. Highway	State Highway
Number	4	1	20

(c) Thermoplastic Pipe Culverts

Roadway Type	Interstate Highway	U.S. Highway	State Highway	Others
Number	0	3	4	3

Table 5.12: ADT Classification of Selected Highway Culverts

(a) Concrete Culverts

ADT	< 1,000	1,000 to 4,000	4,000 to 10,000	10,000 to 30,000	> 30,000
Number	7	13	2	0	3

(b) Metal Culverts

ADT	< 1,000	1,000 to 4,000	4,000 to 10,000	10,000 to 30,000	> 30,000
Number	3	11	5	3	3

[Note] The ADT data were not readily available for the thermoplastic pipe culvert sites.

5.3.8 Environmental Condition Characterization

Key environmental conditions at highway culvert sites, such as pH of drainage water and abrasiveness of the flow, were summarized in a series of charts in the ODOT culvert durability study report (ODOT 1982). By consulting these charts, basic environmental site characterization can be obtained. Results are presented in Table 5.13. According to the table, only one (4%) of the concrete culverts was supposed to be regularly impacted by acidic drainage, while abrasive bed material can be present at up to

72% of the concrete culvert sites. Among the twenty-five metal culverts, only two structures (8%) may be frequently in contact with acidic drainage flow, while abrasive bed material can be present at about a half of the metal culvert sites. None of the thermoplastic pipe culverts may be in the area characterized with acid drainage flow. In contrast, abrasive bed material may be present at a majority of the thermoplastic pipe culvert sites

Table 5.13: Basic Environmental Conditions at Selected Highway Culverts

(a) Concrete Culverts

Parameters	pH of Drainage Water:			Presence of Abrasive Material:	
	< 6	6 to 8	> 8	Yes	No
Number	1	22	2	18	7

(b) Metal Culverts

Parameters	pH of Drainage Water:			Presence of Abrasive Material:	
	< 6	6 to 8	> 8	Yes	No
Number	2	22	1	12	13

(c) Thermoplastic Pipe Culverts

Parameters	pH of Drainage Water:			Presence of Abrasive Material:	
	< 6	6 to 8	> 8	Yes	No
Number	0	10	0	9	1

[Note] The following charts in ODOT Culvert Durability Study Report (1982) were consulted:
- Figure 41: Map of Ohio Showing Type of Abrasive Material Present
- Figure 42: Average Water pH Contour Map of Ohio

5.3.9 Summary of Culvert Characterizations

This section presents composite characterization data for the culverts inspected in the current project. Tables 5.14.(a) through (c) summarize the information. According to Table 5.14.(a), all the concrete culverts at advanced age were the slab-on-top type. Based on Figure 41 (ODOT, 1982), abrasive bed material may exist at 72% of the concrete culvert sites. Combining with the information presented in Figure 42 (ODOT, 1982), only one structure is supposed to be subjected to acidic and possibly abrasive drainage flow. All of the advanced-age concrete culvert structures were under shallow covers.

According to Table 5.14.(b), pipe-arch structures are located in Districts 1, 8, 9, and 10. Most of the circular metal pipe culverts were at ages between 40 and 60 years. Referring to Figure 41 (ODOT, 1982), abrasive bed material may be present at about half (48%) of the metal culvert sites. And, the metal culvert may be often subjected to acid drainage at three of these sites. Both of the advanced-age metal culvert structures were under shallow covers. The metal culverts with age between 40 and 60 years were under a wide range of soil cover thickness.

According to Table 5.14.(c), only one of the six HDPE pipes was older than 20 years and none of the four PVC pipes were older than 20 years. Based on Figure 41 (ODOT, 1982), abrasive bed material may be present at most of the sites. However, six of the ten sites are situated within a major highway construction project area. Construction activities can alter the original environmental conditions. Based on Figure 42 (ODOT, 1982), none of the structures are supposed to be normally subjected to acidic drainage. The flow condition was judged abrasive at only one of these HDPE pipe culvert sites. The 23-year old HDPE pipe culvert (NOB-145-3.59) had been serving under abrasive drainage flow and shallow cover.

Table 5.14.(a): Characterizations of Concrete Culvert Sites

Dist.	Culvert I.D.	Shape:			Age Group:			pH:		Mat'l:		Soil Cover:		
		P	B	O	1	2	3	A	N	P	N	S	M	D
01	PUT-189-10.5		●		●				●	●		●		
01	HAN-224-6.84	●			●				●		●		●	
01	WYA-103-1.06		●		●				●		●	●		
05	LIC-70-13.52	●			●				●	●			●	
05	COS-93-11.54		●			NA			●	●		●		
06	MAD-29-11.37		●			●			●	●		●		
06	MAD-142-4.30		●				●		●		●	●		
06	FAY-753-2.09		●			NA			●	●		●		
06	PIK-335-5.18		●			NA			●		●	●		
08	CLI-28-7.84		●			●			●	●		●		
08	BUT-126-2.58		●		●				●	●		●		
08	GRE-380-5.03	●				●			●	●		●		
09	HIG-124-25.75			●		NA			●		●	●		
10	HOC-216-1.99		●		●				●	●		●		
10	HOC-78-1.05		●				●		●	●		●		
10	HOC-216-3.25		●			●			●	●		●		
10	HOC-216-3.43		●			●			●	●		●		
10	MRG-78-11.34		●				●		●	●		●		
10	MRG-78-24.97		●		●				●		●	●		
10	VIN-56-6.85		●				●	●		●		●		
10	MEI-338-16.42		●				●		●		●	●		
10	ATH-278-0.25			●	●				●	●		●		
10	MRG-60-19.95		●			●			●	●		●		
12	CUY-480-0.5	●			●				●	●		●		
12	CUY-422-15.2	●			●				●	●		●		

[Notes] Shape ……………... [P] = Circular Pipe; [B] = Slab-On-Top (Three-Sided Box) or Box (Four-Sided Box); [O] = Other (ex. Ellipse).

Age Group …...…..… [1] = 1 – 50 years; [2] = 50 to 75 years; [3] = More than 75 years.

pH Group …...……... [A] = Acidic (pH ≤ 6); [N] = Non-acidic --- based on Figure 42 in ODOT Durability Study Report (1982).

Material ……….…... [P] = Abrasive material present; [N] = Abrasive material not present --- Based on Fig. 41 (ODOT, 1982).

Soil Cover …………. [S] = Low (< 10 ft.); [M] = Medium (10 to 20 ft.); [D] = Deep (> 20 ft.).

1 ft = 0.305 m.

Table 5.14.(b): Characterizations of Metal Culvert Sites

Dist.	Culvert I.D.	Shape:		Age Group:			pH Group:		Abrasive Material:		Soil Cover Group:		
		P	PA	1	2	3	A	N	P	N	S	M	D
01	PAU-66-2.44	●			●			●		●	●		
01	DEF-18-20.60		●			●		●		●	●		
01	PUT-15-14.78	●			●			●		●	●		
05	LIC-16-13.66	●			NA			●		●		●	
05	GUE-70-8.94	●			●			●		●			●
05	MUS-93-1.76	●			●			●	●				●
05	GUE-77-7.85R	●			●			●		●			●
05	KNO-95-0.08	●			NA			●	●		●		
06	MAD-29-8.80	●			NA			●	●		●		
08	CLI-124-0.03		●		●			●		●	●		
09	HIG-50-19.82	●			NA			●	●		●		
09	JAC-124-17.12		●		NA		●		●		●		
09	PIK-32-15.96	●			NA			●	●			●	
09	ADA-247-11.87	●			NA			●		●	●		
10	HOC-595-2.85		●		●		●		●		●		
10	HOC-664-17.16		●		●		●			●	●		
10	HOC-664-22.40	●			●		●			●		●	
10	GAL-7-21.30	●				●		●		●	●		
10	MEI-681-7.94	●			●			●	●		●		
10	MEI-681-13.96		●		●			●		●	●		
10	HOC-595-4.57		●		●		●		●		●		
10	WAS-339-15.25	●			●			●	●		●		
10	WAS-60-4.84	●			●			●	●				●
12	LAK-90-14.00	●			●			●		●			●
12	LAK-90-4.20	●			●			●	●		●		●

[Notes] Shape …………..… [P] = Pipe; [PA] = Pipe-Arch.
Age Group …..….… [1] = 1 – 40 years; [2] = 40 to 60 years; [3] = More than 60 years.
pH Group …..…….. [A] = Acidic (pH ≤ 6); [N] = Non-acidic --- based on Figure 42 (ODOT, 1982).
Abrasive Material …. [P] = Abrasive material present; [N] = Abrasive material not present --- Based on Figure 41 (ODOT, 1982).
Soil Cover ……..…. [S] = Low (< 10 ft.); [M] = Medium (10 to 20 ft.); [D] = Deep (> 20 ft.).

1 ft = 0.305 m.

Table 5.14.(c): Characterization of Thermoplastic Pipe Culvert Sites

Dist.	Culvert I.D.	Material:		Age Group:			pH Group:		Abrasive Material:		Soil Cover Group:		
		HDPE	PVC	1	2	3	A	N	P	N	S	M	D
05	FAI-33b-Sta. 446+92	●		●				●	●			●	
05	PER-13-11.14	●		●				●	●		●		
05	FAI-33b-Sta. 587+96		●	●				●	●			●	
05	FAI-22-Sta. 17+20		●	●				●	●				●
05	FAI-33b-SR18-Sta. 86+00	●		●				●	●			●	
05	FAI-33b-SR18-Sta. 96+00		●					●	●		●		
05	FAI-33b-Ramp J (Sta. 488+07)		●	●				●	●			●	
10	MEI-124-30.17	●		●				●	●		●		
10	HOC-327-2.70	●		●				●		●	●		
10	NOB-145-3.59	●			●			●	●		●		

[Notes] Age Group …..…… [1] = 1 – 20 years; [2] = 20 to 40 years; [3] = More than 40 years.
pH Group …...….…. [A] = Acidic (pH ≤ 6); [N] = Non-acidic --- based on Figure 42 (ODOT, 1982).
Abrasive Material …. [P] = Abrasive material present; [N] = Abrasive material not present --- Based on Figure 41 (ODOT, 1982).
Soil Cover ……..…. [S] = Low (< 10 ft.); [M] = Medium (10 to 20 ft.); [D] = Deep (> 20 ft.).
1 ft = 0.305 m.

5.4 ALTERNATE CULVERT RATING SYSTEMS

During the literature review phase of the current project, it was found that in some DOTs' inspection procedures the inlet and outlet end sections were evaluated separately from the main barrel section. However, the highway culvert inspection/rating procedures outlined in the ODOT Culvert Management Manual (2003) did not treat the end sections as separate entities and considered them as part of the whole structure. The authors felt that the end sections should be treated separately, because these sections were impacted more by the drainage flow characteristics and UV light and less by the dead and live loads coming from the roadway embankment. This was a starting point in an effort to propose an alternate, higher-resolution culvert rating system to identify possibly other important needed inspection items. The alternate system can be viewed as an enhanced version of the new culvert rating system developed by ODOT (ODOT, 2003).

In the proposed high-resolution system, a complete set of inspection data for any culvert structure is grouped into inventory data, primary data, and secondary data. Items within the inventory or background data are those that can be obtained from a district office as background information and can be used to locate the structure in the field. The primary and secondary data were collected during the actual field inspection work conducted at the culvert site. Items in the primary data indicate directly the existing conditions of the culvert structure. Items in the secondary data reflect the conditions of the structures/features (such as headwalls, embankment slopes, …) surrounding the culvert and serve as indirect measures of the culvert performance. Tables 5.15 through 5.17 present the complete set of data required for inspecting concrete, metal, and thermoplastic pipe culverts, respectively. The items in the primary data differ somewhat from one type of culvert to another. Appendices B through D contain copies of the field inspection date sheets used for concrete, metal, and thermoplastic pipe culverts, respectively.

Table 5.15: ORITE Data Collection for Concrete Culverts

(a) Inventory Data

Location (District, County, Roadway, Straight Line Mileage, …).			
Culvert Material	Age (Year Built)	Type of Protective Coating	
Shape	Rise	Span	Length
Wall Thickness	No. of Cells	No. of Joints	Slope
Max. Height of Cover	Skew Angle	Inlet End Treatment	Outlet End Treatment
Hydraulic Capacity	Channel Protection	ADT	Modifications
Past Inspection & Maintenance Records			

Table 5.15 (cont'd)

(b) Primary Data

Actual Rise	Actual Span	**Inlet End Conditions**	**Outlet End Conditions**
Actual Wall Thickness	**Material Conditions in Main Barrel**		Sounding (by a hammer)
Vertical Alignment (Settlement)	**Horizontal Alignment**		**Joint Conditions**
Conditions of Protective Coating	**Footings**		**Invert Paving**

(c) Secondary Data

Conditions of Roadway Surface		**Conditions of Guardrails & Posts**	
Conditions of Embankment Slopes		**Conditions of Headwall at Inlet End**	
Conditions of Headwall at Outlet End		**Sediment Depth Inside Culvert**	
Channel Alignment	**Channel Obstruction**	**Channel Scour**	**Channel Protection**
Drainage Flow Velocity		Abrasive Conditions	
Chemical Analysis Results on Water Sample		pH of Drainage Water	Level of Inspection

[Note] Items in bold face letters are rated in 1-9 scale.

Table 5.16: ORITE Data Collection for Metal Culverts

(a) Inventory Data

Location (District, County, Roadway, Straight Line Mileage, …).			
Culvert Material	Age (Year Built)	Type of Protective Coating	
Shape	Rise	Span	Length
Wall Thickness	No. of Cells	Slope	Skew Angle
Max. Height of Cover	Inlet End Treatment	Outlet End Treatment	Hydraulic Capacity
Channel Protection	ADT	Modifications	Data on Invert Paving
Data on Backfill Soil	Trench Dimensions	Past Inspection & Maintenance Records	

(b) Primary Data

Actual Rise & Span	Other Cross-Sectional Dimensions		**Deflections**
Shape Evaluation	**Inlet End Conditions**	**Outlet End Conditions**	Actual Wall Thickness
Material Conditions	**Horizontal Alignment**	**Vertical Alignment (Settlement)**	
Conditions of Seams	**Conditions of Protective Coating**	**Conditions of Invert Paving**	
Conditions of Footings			

(c) Secondary Data

Conditions of Roadway Surface		**Conditions of Guardrails & Posts**	
Conditions of Embankment Slopes		**Conditions of Headwall at Inlet End**	
Conditions of Headwall at Outlet End		**Sediment Depth Inside Culvert**	
Channel Alignment	**Channel Blockage**	**Channel Scour**	**Channel Protection**
Drainage Flow Velocity		Abrasive Conditions	
Chemical Analysis Results on Water Sample		pH of Drainage Water	Level of Inspection

[Note] Items in bold face letters are rated in 1-9 scale.

Table 5.17: ORITE Data Collection for Thermoplastic Pipe Culverts

(a) Inventory Data

Location (District, County, Roadway, Straight Line Mileage, …).			
Culvert Material	Age (Year Built)	Manufacturer	Product Name
Diameter	Length	No. of Cells	Wall Thickness
Type of Joint	No. of Joints	Slope	Max. Height of Cover
Skew Angle	Inlet End Treatment	Outlet End Treatment	Hydraulic Capacity
Channel Protection	ADT	Past Inspection & Maintenance Records	

Table 5.17 (cont'd)

(b) Primary Data

Actual Rise & Span	Other Cross-Sectional Dimensions		**Deflections**
Shape Evaluation	**Inlet End Conditions**	**Outlet End Conditions**	Actual Wall Thickness
Material Conditions	**Horizontal Alignment**	**Vertical Alignment (Settlement)**	
Conditions of Joints			

(c) Secondary Data

Conditions of Roadway Surface		**Conditions of Guardrails & Posts**	
Conditions of Embankment Slopes		**Conditions of Headwall at Inlet End**	
Conditions of Headwall at Outlet End		**Sediment Depth Inside Culvert**	
Channel Alignment	**Channel Blockage**	**Channel Scour**	**Channel Protection**
Drainage Flow Velocity		Abrasive Conditions	
Chemical Analysis Results on Water Sample		pH of Drainage Water	Level of Inspection

[Note] Items in bold face letters are rated in 1-9 scale.

There are many similarities between the ODOT and the proposed systems in rating these items. Also, there are clear differences, besides the separate evaluation of culvert ends. Table 5.18 summarizes the similarities and differences between the two culvert rating systems. The proposed system aims for higher resolutions in the data collected in the field by:

- Rating the general material conditions in each distinct region (crown, sides, invert) of the culvert.

- Rating the conditions at the joints/seams in each distinct region (crown, sides, invert) of the culvert.

- Rating the conditions of each headwall in terms of cracking, deterioration, and movement.

Tables 5.19 through 5.23 are added here to further illustrate the degree of high resolution that the proposed system employed. This resolution includes rating of the protective coating and invert paving (Table 5.19), the culvert inlet and outlet sections (Table 5.20), footings (Table 5.21), headwalls/wingwalls (Table 5.22), and channel

(Table 5.23). Without the higher resolution provided, it may be difficult to come up with an accurate overall rating of the actual condition, unless the field condition match one of the descriptions addressed by the ODOT rating system.

Table 5.18: Comparisons Between ODOT and Proposed Culvert Rating Systems

Item	ODOT Rating System	Proposed Rating System
Material (General)	Address the overall general material conditions within the culvert.	Rate the general conditions of the culvert material in the crown region (top), springline region (abutment), and invert region separately.
Material (General) for Thermoplastic Pipe	Rate the general material conditions in terms of tearing only.	Rate the general material conditions in terms of wall buckling as well as cracking.
Inlet End Outlet End	Not rated separately from the main barrel. Briefly addressed under Material (General) for metal culverts only.	Rate the inlet end and outlet end sections independently from the main barrel.
Culvert Alignment	Consider the overall level of alignment problems as one.	Address the horizontal and vertical alignment separately.
Culvert Shape (Deflection)*	Degree of deflection is rated in terms of horizontal deflection.	Use of vertical deflection is emphasized.
Seams & Joints	Overall conditions of the seams or joints are rated.	Rate the seam/joint conditions in the crown region, springline region, and invert region separately.
Top Slab**	Rate for three-sided and four-sided box structures only.	See the information listed above under "Material (General)."
Abutments**	Rate for three-sided and four-sided box structures only.	See the information listed above under "Material (General)."
Sediment Inside Culvert	Not addressed/Not rated.	A rating system is set up specifically for evaluating the siltation inside the culvert.
Headwalls	Overall conditions of the headwalls at the site are rated.	Conditions of each headwall are rated in terms of material, cracking, and movement.
Protective Coating	Not addressed/Not rated.	Rate the integrity of the protective coating.
Invert Pavement	Invert pavement not addressed/Not rated.	Rate the integrity of the invert pavement in a same way as the integrity of the protective coating.
Footing	Footing not addressed/Not rated.	Rate the conditions of the footing in terms of deterioration of concrete and movement.
Channel Alignment	Address even the twin culvert situation.	Modified the ODOT rating system slightly.
Channel Protection	Developed 1 to 9 rating scale.	Modified the ODOT rating system slightly.
Waterway Blockage	It is unclear whether this item deals primarily with the blockage in the culvert or in the stream.	Adopted the ODOT rating system. Interpreted as an item on channel blockage.
Scour	Address footing problem briefly.	Adopted the ODOT rating system.
Roadway Surface	Developed 1 to 9 rating scale.	Adopted the ODOT rating system.
Guardrail	Developed 1 to 9 rating scale.	Adopted the ODOT rating system.
Embankment	Developed 1 to 9 rating scale.	Modified the ODOT rating system slightly. The embankment slopes on inlet and outlet sides are rated separately.

[Notes] * This item is not addressed for rigid (concrete) culverts.
** These items are only used in three-sided and four-sided concrete culverts.

Table 5.19: Proposed Rating System for Protective Coating & Invert Paving

Rating	Descriptions
9 (Excellent)	Good, intact; No signs of delamination.
8 (Very Good)	Generally good; intact; Minor delamination (hairline cracks) at one location.
7 (Good)	Minor delamination (hairline cracks) of coating at isolated locations.
6 (Fair)	Minor delamination (hairline cracks) of coating at numerous locations.
5 (Fair-Marginal)	Moderate delamination (extensive cracking & peeling) of coating at a few isolated locations as well as minor delamination (hairline cracks) at numerous locations.
4 (Marginal)	Moderate delamination (extensive cracking & peeling) at numerous locations.
3 (Poor)	Coating or paving removed over a large area at isolated locations.
2 (Very Poor)	Coating or paving removed over a large area at numerous locations.
1 (Failure)	Coating or paving is only present in small areas inside the culvert.
0 (Failure)	Coating or paving is totally non-existent in the culvert.

Table 5.20: Proposed Rating System for Culvert Inlet & Outlet Sections

Rating	Condition
9 (Excellent)	New condition.
8 (Very Good)	Good, no signs of material deteriorations (no cracking, no spalling, no scaling); No movement (dropping off or lifting up) of the culvert end; No scouring underneath.
7 (Good)	Signs of minor material deterioration (cracking, spalling, scaling); No movement (dropping off or lifting up) of the culvert end; Minor scouring at the end.
6 (Fair)	Signs of minor material deterioration (cracking, spalling, scaling), Minor movement (dropping off or lifting up) of the culvert end; Minor scouring at the end.
5 (Fair-Marginal)	Moderate deterioration of the culvert material (cracking, spalling, scaling), Minor movement of the pipe end; Moderate scouring at the end.
4 (Marginal)	(No specific conditions addressed).
3 (Poor)	Moderate deterioration of the culvert material (cracking, spalling, scaling); Moderate movement of the pipe end; Moderate scouring at the end.
2 (Very Poor)	Significant degradation of the culvert material (cracking, spalling, scaling); Severe movement of the end; Severe scouring at the end at the end.
1 (Critical)	Culvert end section has partially collapsed or collapse is imminent.
0 (Failure)	Total failure of the culvert end section and fill around it.

[Note] End section is generally defined as the first/last 5' section of the culvert structure.

Table 5.21: Proposed Rating System for Footings

According to ODOT Culvert Inspection Manual (1990).

Rating	Descriptions
9 (Excellent)	New condition.
8 (Very Good)	Good with no erosion.
7 (Good)	Moderate erosion, causing differential settlement and minor cracking in footing.
6 (Fair)	Moderate cracking and differential settlement of footing due to extensive erosion.
5 (Fair-Marginal)	Significant undercutting of footing and extreme differential settlement; Major cracking in footing.
4 (Marginal)	Rotated due to erosion and undercutting; settlement has caused damage to culvert.
3 (Poor)	Rotated; severely undercut; Major cracking and spalling.
2 (Very Poor)	Severe differential settlement has caused distortion and kinking of culvert.
1 (Failure)	Culvert has partially failed or collapse is imminent.
0 (Failure)	Culvert has failed completely.

Table 5.22: Proposed Rating System for Headwall/Wingwall

Rating	Descriptions for:		
	Cracking	Deterioration (Spalling, Delamination, …)	Movement (Settlement, Rotation, …)
9 (Excellent)	New condition.	New condition.	New condition.
8 (Very Good)	Aged concrete; Some discoloration; No cracks.	No signs of material deterioration. Minor discoloration.	No movement.
7 (Good)	A few to several hairline cracks detected.	Light scaling (less than 1/8 in or 3 mm deep); Slight loss of mortar. Aggregates not exposed.	Slight movement on one side (or in one area).
6 (Satisfactory)	Extensive hairline cracking. No rebars exposed.	Minor delamination or spalling along cracks. Surface scaling 1/8 to 1/4 in (3 to 6 mm) deep. Some small aggregates lost.	Slight movement on both sides.
5 (Fair)	One of the cracks is at least 0.1 inch (3 mm) wide.	Moderate delamination, Moderate spalling. Rebars beginning to surface.	Moderate movement on one side (or in one area).
4 (Poor)	A few major cracks in addition to some hairline cracks.	Moderate spalling/scaling at isolated locations. One side of the first layer of rebars exposed .	Moderate movement on both sides.
3 (Serious)	Several major cracks running through the wall.	Moderate scaling has occurred at many locations. First layer of rebars exposed completely. Moderate degree of concrete softening.	Severe movement on one side (or in one area). Rotation up to 4 in per foot (335 mm per m).
2 (Critical)	Numerous major cracks. Some regions are becoming almost loose.	Severe spalling/scaling has occurred extensively.	Severe movement on both sides.
1 (Critical)	Major portion of the headwall gone; Rebars exposed extensively and corroded severely.		Headwall has partially failed.
0 (Failure)	Headwall has collapsed completely.		

[Note] Rate the headwall at inlet & outlet separately.

Table 5.23: Proposed Rating System for Channel (General)

According to ODOT Culvert Inspection Manual (Draft 2003) – Modified Slightly.

Rating	Descriptions for: Alignment	Scouring	Obstruction
9 (Excellent)	New conditions. Channel is straight for more than 100' at both upstream & downstream. No adverse conditions detected.	New conditions. No scouring at either inlet or outlet ends.	New conditions. No debris or sediment accumulation anywhere.
8 (Very Good)	Channel straight for 50' to 100' at one end, for more than 100' at other end.	Very minor (< 6" deep) scouring at both inlet and outlet ends.	Minor debris accumulation.
7 (Good)	Channel is straight for 50' to 100' at both ends; Minor sediment accumulation; Bush growing.	Minor (6" to 12" deep) scouring at one end.	Minor sedimentation and debris accumulation; Up to 5% blockage of channel opening.
6 (Satisfactory)	Channel is straight for 20' to 50' at one end; Channel is curved by 20˚ to 40˚ angle near inlet; Deposit causing channel to split.	Minor (6" to 12" deep) scouring at both ends; Top of footings is exposed.	Minor sedimentation and debris. Up to 10% blockage of channel opening; Bush or tree growing in channel.
5 (Fair)	Channel is straight for 20' to 50' at both ends; Channel curved by 40˚ to 50˚ angle near inlet; Flow hitting outside headwall; Stream meandered; Signs of Bank erosion.	Minor (6" to 12" deep) scouring at one end; Moderate (12" to 24" deep) scouring at the other end; Footings along the side are exposed.	Waterway moderately (up to 25%) restricted by tree, shrubs, or sedimentation; Bush or tree growing in channel.
4 (Poor)	Channel curved by 50˚ to 70˚ angle near inlet; Flow enters culvert by other means than design opening; Signs of Bank erosion.	Severe (2' to 3' deep) scouring at one end; Less scouring at the other end; Bottom of footings is exposed; Not undermining cutoff walls/headwalls.	Partial (up to 50%) blockage of channel opening; Large debris in the waterway; Occasional overtopping of roadway.
3 (Serious)	Channel curved by 70˚ to 90˚ turn near inlet; Erosion behind wingwalls; Erosion of embankment encroaching on roadway.	Major (> 3' deep) scouring at one end; Cutoff walls and/or headwalls being undermined; Footings are undermined; Structure has been displaced or settled.	Mass drift accumulation has restricted 75% of channel opening; Occasional overtopping of roadway.
2 (Critical)	Channel flow piping around culvert; Erosion of embankment encroaching on roadway.	Structure or roadway weakened by bank erosion or scour problem; danger of collapse sometime in the future.	Culvert waterway blocked up to 85% by mass drift accumulation; Frequent overtopping of roadway w/ significant traffic delays.
1 (Failure Imminent)	No channel flow enters culvert; Severe piping problem around culvert; Road may be closed due to channel failure.	Structure or approach weakened; danger of immediate collapse.	Culvert waterway 100% blocked by deposits; Water pooling outside and not flowing through pipe; Road may be closed due to channel failure.
0 (Failed)	Pipe has collapsed.	Pipe has collapsed.	Pipe has collapsed.
- 1 (Under Construction)	Cannot be rated; still under construction.		

[Note] 1' = 0.305 m; 1" = 25 mm.

5.5 FIELD INSPECTION PROGRAM

5.5.1 Inspection Team

The core of the field culvert inspection team comprised of two personnel from ORITE and two personnel from the Subcontractor (Jobes Henderson & Associates). The ORITE personnel had some prior culvert inspection experience as well as an in-depth research (field instrumentation and monitoring, theoretical/numerical analysis) experience related to corrugated metal culverts, concrete pipes, and thermoplastic pipes. The Subcontractor brought more industry-oriented experience in culvert/bridge inspections and design work. During the course of the project, an unanticipated personnel change occurred once with the Subcontractor. However, the same core ORITE personnel remained in the team throughout the entire inspection phase and visited and evaluated all sixty culvert sites.

5.5.2 List of Equipment

Equipment the inspection team utilized in the field can be grouped into general items (which are readily available and used routinely in every culvert inspection) and specialized items (which may be used only at selected culvert sites). Table 5.24.(a) lists the general items. The laser distance meter was useful in obtaining the total length of any long culvert structure. The surveyor's level rod was used to estimate the height of soil cover. The hand-level was used to judge if the headwalls were tilted or not. The road signs were posted along the traffic lane(s) in each direction to alert motorists that the field inspection work was in progress. The micrometer was used to measure the wall thickness of metal plates. Water pH-meter provided the pH reading of the drainage water at the culvert inlet. The C-clamps, strings, and folding ruler were used to obtain detailed cross-sectional dimensions. Table 5.24.(b) lists the specialized items. A water DO meter was used to measure the dissolved oxygen level in the drainage flow. The team transported the remote video inspection system whenever they were scheduled to inspect culverts that were less than 4' in rise.

Table 5.24: List of Field Equipment

(a) General Items

Road Map	Directional Compass	Hip-boots
Hard Hats	Safety Vests	Cell Phone
Gloves	Flash Lights	Camera (Digital)
Clipboard	Data Sheets	Pens
ODOT Culvert Manual	Road Signs	25' Measuring Tape (Steel)
Laser Distance Meter	100' Tape (Fiberglass)	Folding Ruler (Wooden)
Survey Level Rod	Hand Level	Micrometer
Chipping Hammer	Plumb-bob	C-Clamps
Wire & Strings	Shovels	Steel Rod
Spray Pain & Magic Marker	Duct Tape	Step Ladder
Water Sample Bottles	Extra Batteries	First Aid Kit
Water pH Meter	Extension Cord	Water Sample Bottles

(b) Specialized Items

Water DO Analyzer	Digital Thermometer	Portable GPS Device
Soil Sampler	Skate Board	Power Drill
Power Generator	Hole Saws & Drill Bits	Electric Fan
---	Remote Video Inspection System	

5.5.3 Field Inspection Method

Typically, about one week prior to each inspection the team members identified the next inspection date and exchanged inventory data (location, type, size, age, length, soil cover, maintenance notes, …) on a couple of target culverts selected from the pool of sixty structures. As needed, the team notified the DOT and other officials about their field inspection schedule. As the inspection date approached, the members closely monitored the weather and roadway condition data for the area where the culverts were located. Inspection work at a culvert site typically proceeded as follows:

1) Confirm the type, size, and location of the culvert structure.
2) Set up the roadway signs for each traffic direction.
3) Assess basic environmental conditions (pH, DO, flow velocity, abrasiveness of the flow) of the drainage flow and the channel at the inlet end. Take photographs of the channel. Obtain a bottle sample of the drainage flow at culvert inlet for lab analysis.
4) Rate the headwall, embankment slope, and culvert end (the first 5-ft. section from the inlet end) while in the culvert inlet area. Take photographs of each of these inspection items.
5) Walk over the entire barrel section of the culvert. Measure the total length of the structure. Observe conditions of the material surface, seams/joints, sedimentation. If the structure is long, divide the structure into sections. Rate the conditions of the structure in each section.
6) Take cross-sectional shape measurements inside the culvert for metal and thermoplastic pipe culverts. (see Table 5.25 and Figure 5.4 for measurement types).
7) Assess the horizontal and vertical alignments, while walking toward the outlet end.
8) Rate the headwall, embankment slope, and culvert end (the last 5-ft. section from the inlet end) while in the culvert outlet area. Take photographs of each of these inspection items.

9) Walk back through the culvert structure toward the inlet end, if possible, to confirm the previous inspection results and check if all major site conditions were addressed.

10) Estimate the height of cover. Assess the pavement surface and guardrail conditions. Take photographs of each of these inspection items using a digital camera. Draw sketches, if necessary, to summarize the field conditions that were difficult to capture in the photographs.

The tasks were divided among the team members to conduct the field inspection consistently and efficiently. Member #1 from ORITE was responsible for taking environmental (pH, DO, and temperate) readings of the drainage water as well as securing a bottle sample of the drainage water. Two members (Member #2 from ORITE, Member #1 from the Subcontractor) inspected/rated various conditions at each culvert site and filled out the ORITE field inspection data sheets using the ORITE rating tables. These two members worked closely on every inspection item and discussed their differences in some cases to arrive at the final set of rating scores. They also worked together to obtain dimensional measurements inside the culvert. The fourth team member (Member #2 from the Subcontractor) functioned as a photographer at each site.

Table 5.25: Cross-Sectional Shape Dimensions Taken Inside Non-Rigid Culverts

(a) Circular Pipe Culverts

Vertical Diameter (Rise)	Horizontal Diameter (Span)

(b) Pipe-Arch Culverts

Rise	Span	Right or Left Span
Top Mid-Ordinate	Right Chord	Right Mid-Ordinate
Left Chord	Left Mid-Ordinate	

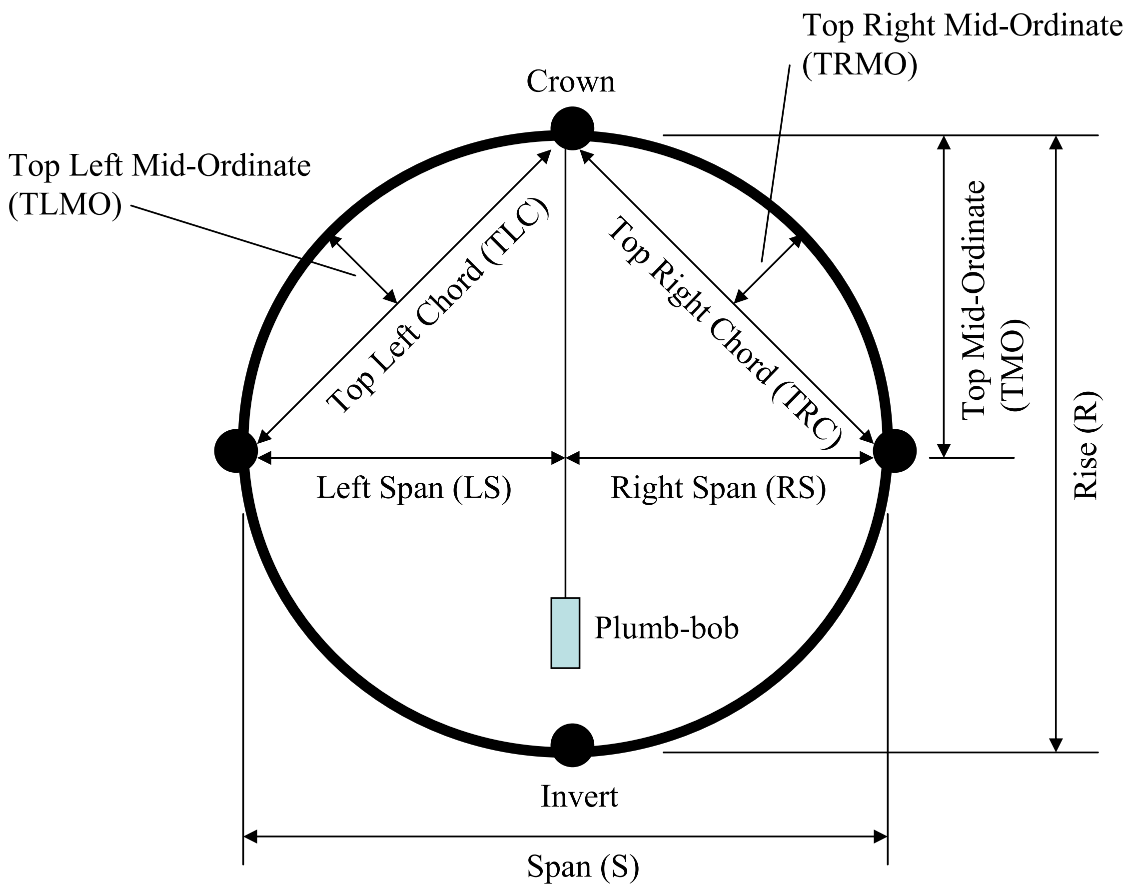


Figure 5.4: Definitions of Various Cross-Sectional Dimensions

5.5.4 Post-Inspection Data Management

After each field inspection work, the ORITE personnel were engaged in post-inspection data management activities in the office, which included:

- Writing of a project memo that describes details of the field inspection activities and findings at each culvert site.
- Filing of the ODOT Culvert Inventory & Inspection data sheets, based on the data available from the ORITE data sheets. It was relatively easy to translate the rating scores on the proposed system to those on the ODOT culvert rating

procedure, since they shared many common elements and also the proposed system had somewhat higher resolutions.

- Copying (to produce back-up duplicates) and filing of all the data sheets.
- Entry of all the inspection data into computer database files.
- Processing of all the digital camera pictures by saving them on a PC hard-drive and a CD-ROM disc.
- Analysis of the drainage water sample at the environmental laboratory.

CHAPTER 6: FINDINGS OF CULVERT INSPECTION PROGRAM

6.1 SCHEDULE OF CULVERT INSPECTIONS

Inspection of the highway culverts in Ohio was conducted over a 14-month period from April 2003 to June 2004. Table 6.1 summarizes the number of culverts inspected during the period for each major culvert type. No culverts were inspected in January, February, and March of 2004 due to increment winter weather conditions.

Table 6.1: Completion Rates of Field Culvert Inspection Work

Months	1-2	3-4	5-6	7-8	9-10	11-12	13-14	Total
Concrete	2	9	1	4	4	0	5	25
Metal	7	5	1	6	4	0	2	25
Thermoplastic	1	0	6	1	0	0	2	10

[Note] The value in each cell indicates the number of culverts inspected in each 2-month period.

6.2 FINDINGS

This section presents specific conditions detected at each culvert site during the field inspection phase of the project. First, the basic environmental conditions found at all the sites are summarized. Then, the in-service conditions of the culvert structures and surrounding structural elements (such as headwalls, roadway surface, embankment slopes, …) are listed for each major culvert type. Detailed notes on each culvert site are presented to describe the field conditions detected at each site in detail. Discussions follow the data presentations to point out the trends that existed among the field inspection data. Appendices E and F, both contained in the attached CD-ROM disk, present the data collected in the EXCEL spreadsheets and photo-documentation of each culvert conditions.

6.2.1 Environmental Conditions

The basic environmental conditions encountered at the inspected culvert sites are summarized in Table 6.2. The statewide average pH values of the surface drainage flow, presented in Figure 42 of the ODOT Culvert Durability Study Report (ODOT, 1982), were fairly accurate at about 58% of the culvert sites. The ODOT report indicated that abrasive bed material might be present at 63% of the sites. In the field, abrasive drainage flow condition, characterized by relatively rapid normal drainage flow velocity and presence of coarse soil grains, was detected at 1/3 of the sites. Sulfate concentration was below the detection limit of 0.5 mg/L at 44% of the concrete culvert sites. The normal environmental conditions would be represented by pH value close to neutral and sulfate concentration below the detection limit.

Table 6.2: Comparisons of Environmental Conditions

Dist.	Culvert I.D.	Culvert Material	pH of Drainage Water:			Abrasiveness of Flow:		Lab. Sulfate Concentration:
			Field	Lab	ODOT	Field	ODOT	
01	PUT-189-10.5	Concrete	7.6	7.9	7.8	Y	P	40.0 mg/L
01	PAU-66-2.44	Metal	7.7	7.3	7.8	N	U	22.1 mg/L
01	DEF-18-20.6	Metal	7.7	7.0	7.6	N	U	10.9 mg/L
01	PUT-15-14.78	Metal	7.9	7.8	7.8	Y	U	195.4 mg/L
01	HAN-224-6.84	Concrete	7.5	7.4	7.9	N	U	124.6 mg/L
01	WYA-103-1.06	Concrete	7.8	7.7	8.4	N	U	40.6 mg/L
05	LIC-16-13.66	Metal	8.2	7.8	7.5	Y	U	---
05	LIC-70-13.52	Concrete	7.6	7.3	7.5	N	P	< 0.5 mg/L (DL)
05	GUE-70-8.94	Metal	8.2	7.5	7.4	N	U	---
05	MUS-93-1.76	Metal	8.5	7.5	7.1	N	P	< 0.5 mg/L (DL)
05	GUE-77-7.85R	Metal	8.2	NA	7.4	N	U	159.4 mg/L
05	PER-13-11.14	Plastic	7.9	NA	6.6	N	P	9.9 mg/L
05	FAI-33b-Sta. 587+96	Plastic	7.9	NA	7.0	N	P	77.2 mg/L
05	FAI-22-Sta. 17+20	Plastic	8.0	NA	7.0	N	P	20.3 mg/L
05	FAI-33b-SR 18-Sta. 96+0	Plastic	NA	6.9	7.0	N	P	13.1 mg/L
05	FAI-33b-SR 18-Sta. 86+0	Plastic	NA	NA	7.0	N	P	---
05	FAI-33b-Sta. 446+92	Plastic	4.1	7.6	7.0	N	P	---
05	FAI-33b-Ramp J-Sta. 488+0	Plastic	7.8	7.4	7.0	N	P	54.1 mg/L
05	COS-93-11.54	Concrete	7.1	6.9	7.0	N	P	30.9 mg/L
05	KNO-95-0.08	Metal	7.4	7.0	7.5	N	P	---
06	MAD-29-8.80	Metal	8.1	7.6	7.3	Y	P	---
06	MAD-29-11.37	Concrete	8.1	7.6	7.5	N	P	3.2 mg/L
06	MAD-142-4.30	Concrete	7.8	7.6	7.2	N	U	< 0.5 mg/L (DL)
06	FAY-753-2.09	Concrete	7.9	7.9	7.6	N	P	51.4 mg/L

Table 6.2: Comparisons of Environmental Conditions (cont'd)

Dist.	Culvert I.D.	Culvert Material	pH of Drainage Water:			Abrasiveness of Flow:		Sulfate Concentration (Lab):
			Field	Lab	ODOT	Field	ODOT	
06	PIK-335-5.18	Concrete	7.0	7.1	7.2	Y	U	18.6 mg/L
08	CLI-28-7.84	Concrete	NF	7.6	7.4	N	P	< 0.5 mg/L (DL)
08	CLI-124-0.03	Metal	8.8	8.1	7.5	Y	U	---
08	BUT-126-2.58	Concrete	8.2	7.9	8.2	Y	P	43.7 mg/L
08	GRE-380-5.03	Concrete	7.7	7.3	8.0	N	P	18.0 mg/L
09	HIG-50-19.82	Metal	8.3	7.4	7.8	N	P	---
09	JAC-124-17.12	Metal	2.8	2.8	6.5	N	P	---
09	PIK-32-15.96	Metal	6.5	2.1	7.5	N	P	---
09	HIG-124-25.75	Concrete	7.4	7.4	7.5	N	U	17.4 mg/L
09	ADA-247-11.87	Metal	7.1	7.7	8.1	N	U	---
10	HOC-595-2.85	Metal	6.1	NA	6.0	Y	P	
10	HOC-216-1.99	Concrete	6.2	7.6	6.5	N	P	< 0.5 mg/L (DL)
10	HOC-78-1.05	Concrete	6.6	6.8	6.5	N	P	< 0.5 mg/L (DL)
10	HOC-664-17.16	Metal	7.7	7.0	5.8	N	U	---
10	HOC-664-22.40	Metal	7.7	NA	6.0	Y	U	---
10	GAL-7-21.30	Metal	8.0	7.4	7.0	Y	U	---
10	MEG-681-7.94	Metal	7.7	7.3	6.6	Y	P	---
10	MEG-681-13.96	Metal	7.3	7.4	6.5	Y	U	---
10	HOC-595-4.57	Metal	6.8	6.7	6.0	N	P	---
10	HOC-216-3.25	Concrete	6.9	7.6	6.5	N	P	< 0.5 mg/L (DL)
10	HOC-216-3.43	Concrete	7.3	2.9	6.5	N	P	< 0.5 mg/L (DL)
10	MRG-78-11.34	Concrete	8.5	8.0	6.8	N	P	< 0.5 mg/L (DL)
10	MRG-78-24.97	Concrete	8.4	8.0	6.8	Y	U	< 0.5 mg/L (DL)
10	VIN-56-6.85	Concrete	7.4	7.0	5.2	N	P	< 0.5 mg/L (DL)
10	MEG-124-30.17	Plastic	7.6	7.0	6.6	N	P	< 0.5 mg/L (DL)
10	MEG-338-16.42	Concrete	NF	7.1	6.5	N	U	< 0.5 mg/L (DL)
10	WAS-339-15.25	Metal	7.5	7.8	7.6	Y	P	---
10	WAS-60-4.84	Metal	7.8	7.7	8.0	Y	P	---
10	ATH-278-0.25	Concrete	4.9	3.9	6.2	Y	P	249.6 mg/L
10	HOC-327-2.70	Plastic	6.3	7.3	6.3	N	U	---
10	NOB-145-3.59	Plastic	4.6	4.3	7.5	Y	P	---
10	MRG-60-19.95	Concrete	NF	NF	7.0	N	P	---
12	CUY-480-0.5	Concrete	9.0	8.4	7.7	N	P	54.4 mg/L
12	LAK-90-14.0	Metal	8.2	8.2	7.3	Y	U	---
12	LAK-90-4.2	Metal	7.8	7.3	7.3	Y	P	116.7 mg/L
12	CUY-422-15.2	Concrete	7.6	7.8	7.7	N	P	27.2 mg/L

[Notes] pH Values --- NF = No Flow; NA = Not Available.
Abrasiveness of Flow --- Y = Yes; N = No; P = Possible; U = Unlikely.
ODOT information is from the ODOT Culvert Durability Study Report (ODOT, 1982).
Sulfate Concentration --- DL = Detection Limit.

6.2.2 Conditions Detected at Concrete Culvert Sites

During the field inspection program, some specific conditions were observed at the concrete culvert sites. Table 6.3 lists these specific field conditions encountered, and Table 6.4 shows the type of conditions that existed at each concrete culvert site.

Table 6.3: List of Field Conditions Detected at Concrete Culvert Sites

No.	Description of Site-Specific Conditions
01	The roadway surface above the culvert has numerous hairline cracks and small potholes.
02	Moderate to severe deterioration of the concrete is detected on the headwall. Rebars are exposed.
03	Moderate to severe deterioration of the concrete is detected on the top slab. Rebars are exposed.
04	Moderate to severe deterioration of the concrete is detected at the inlet end. Rebars are exposed.
05	Deep gouges are seen near the base of the abutment wall(s).
06	Transverse shear cracks are present on abutment wall(s).
07	Transverse cracks are present on the top slab or near the joint.
08	Voids in the backfill are visible next to the culvert through the joint gaps.
09	Longitudinal cracks are detected within the top region (between shoulders or on top slab).
10	Joint offset is more than 1.5 inches (38 mm) at some joints.
11	Moderate to severe sediment accumulation is detected inside the culvert.
12	A moderate to large scour hole exists in front of the inlet or outlet end.
13	The bottom slab is showing signs of moderate material deteriorations (ex. scaling; cracking; softening).
14	The headwall has failed either partially or completely.
15	Moderate to severe erosion problem is detected behind/around the headwall.
16	The embankment slope is showing signs of slope stability problem. The slope instability has affected the guardrail and pavement.
17	Moderate to severe deterioration of the concrete is detected at the outlet end. Rebars are exposed.
18	Scoring is detected under footings.
19	Backfill is infiltrating through joint opening or holes in the wall.

[Note] The sequential numbers listed in this table are referenced in Table 6.4.

Table 6.4: Existence of Characteristic Conditions at Concrete Culvert Sites

D.	Culvert I.D.	Characteristics Condition No. :																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
01	PUT-189-10.5						●	●											●	
01	HAN-224-6.84		●		●			●										●		●
01	WYA-103-1.06						●												●	
05	LIC-70-13.52		●							●	●									
05	COS-93-11.54	●		●			●													
06	MAD-29-11.37		●																	
06	MAD-142-4.30		●	●	●									●		●				
06	FAY-753-2.09			●			●	●					●					●		
06	PIK-335-5.18						●	●												
08	CLI-28-7.84			●		●														
08	BUT-126-2.58			●	●		●	●			●									
08	GRE-380-4.97							●												
09	HIG-124-25.75																			
10	HOC-216-1.99		●	●	●							●								
10	HOC-78-1.05		●	●	●										●					
10	HOC-216-3.25													●						
10	HOC-216-3.43			●	●							●								

Table 6.4: Existence of Characteristic Conditions at Concrete Culvert Sites (Cont'd)

D.	Culvert I.D.	Characteristic Condition No. :																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
10	MRG-78-11.34						●	●					●							
10	MRG-78-24.97		●	●								●			●	●	●			
10	VIN-56-6.85		●		●							●				●				
10	MEG-338-16.42		●				●	●	●				●			●				
10	ATH-278-0.25																			
10	MRG-60-19.95		●	●	●											●				
12	CUY-480-0.75																	●		
12	CUY-422-15.2																			

[Note] Refer to Table 6.3 for the description of each characteristic field condition.

Frequencies of the specific conditions cited at the concrete culvert sites are summarized in Table 6.5. According to the table, Condition Nos. 2 (headwall deterioration), 3 (top slab deterioration), 4 (inlet end deterioration), 6 (transverse cracking of abutment walls), and 7 (transverse cracking of top slab) were detected more frequently than the other conditions. In contrast, Condition Nos. 1 (roadway surface deterioration), 5 (gouges in abutment wall), 8 (cavity in adjacent soil fill), 9 (longitudinal cracking of top), 16 (embankment slope instability), and 19 (backfill infiltration) were encountered the least frequently.

Table 6.5: Frequency of Conditions Detected at Concrete Culvert Sites

Condition	Frequency	%	Condition	Frequency	%
1	1 (out of 25)	4	11	4 (out of 25)	16
2	10 (out of 25)	40	12	3 (out of 25)	12
3	10 (out of 25)	40	13	2 (out of 25)	8
4	8 (out of 25)	32	14	2 (out of 25)	8
5	1 (out of 25)	4	15	5 (out of 25)	20
6	8 (out of 25)	32	16	1 (out of 25)	4
7	8 (out of 25)	32	17	3 (out of 25)	12
8	1 (out of 25)	4	18	2 (out of 25)	8
9	1 (out of 25)	4	19	1 (out of 25)	4
10	2 (out of 25)	8	---	---	---

More detailed descriptions of the conditions encountered at each of the twenty-five concrete culvert sites follow.

The culvert PUT-189-10.5 (9' or 2.7 m-span cast-in-place concrete slab-on-top) was scheduled for replacement in 2006. This culvert was extended 6 to 7 ft (1.83 to 2.13 m) in each direction. The extension was done in such a way that the culvert became aligned like the letter S. Because of the non-straight horizontal alignment, the drainage flow hit the east abutment wall upon entering the culvert. The headwall at each end had several hairline cracks and signs of moderate spalling. The top slab appeared newer than the abutment walls in the original section in the middle. However, the slab had transverse cracks in the inlet and outlet sections. Also, additional hairline cracks were visible on the top slab under the roadway centerline. The original abutment walls had some major cracks. The east abutment wall had three cracks running either vertically or diagonally over its entire height. Also, it had a horizontal crack right above the wall/footing joint. The west abutment had two vertical and one horizontal cracks. The footing under the east abutment appeared to be scoured due to the impact from the entering drainage flow. The roadway surface appeared relatively new and free of any defects.

The culvert HAN-224-6.84 (6' or 1.83 m diameter RCP) consisted of twenty-five sections of RCP joined together. The inlet end (Section #25) had several cracks mostly in the haunch region. On the bell end, concrete was chipped off from the 3:00 to 6:00 o'clock positions, with the rebars exposed. The outlet end (Section #1) had conditions similar to those found on the inlet end. Transverse cracks were occasionally detected near the joint. There were also numerous spots where the thin layer of concrete delaminated over the rebars through scaling. The pipe sections which had more of this problem were Sections #1, #9, #14, and #17. No longitudinal cracks were detected in the crown region. Backfill was infiltrating into the culvert through a 4-inch (102-mm) opening at the joint between Section #22 and Section #23 (shown in Figure 6.1). The headwall at each end was showing signs of advanced stage of material deterioration (numerous cracks; softening) due to a combination of impacts from moving debris and chloride attack, as seen in Figure 6.2.

Figure 6.1: Backfill Infiltrating Through Joint Opening (HAN-224-6.84)

Figure 6.2: Deteriorated Headwall at Inlet of HAN-224-6.84

Abutment walls inside the culvert WYA-103-1.06 (5' or 1.52 m-span cast-in-place concrete slab-on-top) were not vertical and both tilted toward the backfill. The lower section of the walls was showing signs of moderate spalling. Each wall also had a major horizontal crack running along the culvert length as well as some diagonal cracks. There was a minor scoring underneath the footing of the north abutment wall. The top slab appeared relatively new and had very few hairline cracks under the traffic lanes. The edges of the top slab at the inlet and outlet ends were cracked and soft. At the inlet, the channel made a 90˚ turn, with the flow hitting the extension of the north abutment wall. The roadway surface looked relatively new and free of any defects.

The culvert LIC-70-13.52 (6' or 1.83 m diameter RCP) consisted of fifty-eight sections joined together. At this site, longitudinal hairline cracks were detected within the top section between Section #5 to Section #54 (see Figure 6.3). None of the cracks had iron staining. At some locations, the cracks developed a map pattern, causing small scaling in the area. Section #33 had a 1/8-inch (3-mm) width crack running along its length at the shoulder. The joint offset was as much as 1.5 inches (38 mm) at the joints between Section #11 and Section #12 and joint between Section #32 and Section #33. No signs of backfill infiltration were found anywhere between the ends. The culvert appeared to have a minor sagging in the middle. At each end, one side of the headwall had more cracks and material deteriorations. Only a minor (5 inches or 127 mm deep) scour was detected at the inlet end.

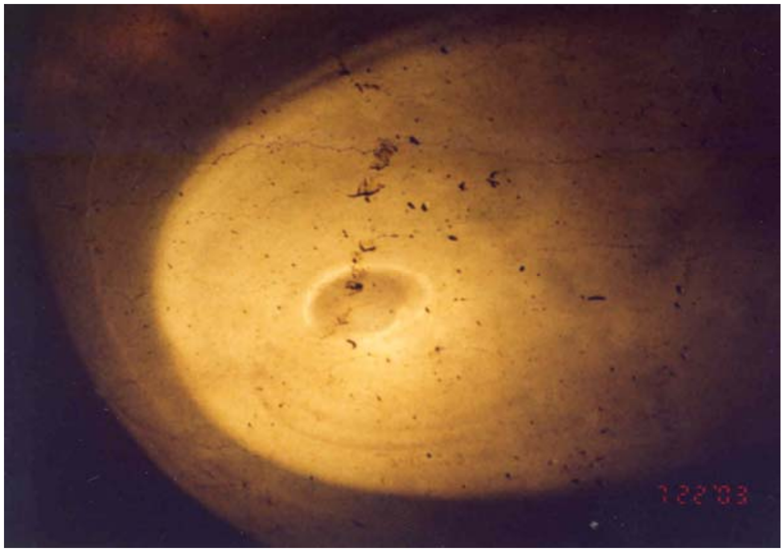


Figure 6.3: Longitudinal Crack Detected at Crown of LIC-70-13.52

The culvert COS-93-11.54 (7’ x 5’ or 2.13 m x 1.52 m cast-in-place concrete box) served more as a flood control. No drainage flow was flowing through the culvert during the inspection. Two notable conditions existed inside the culvert. First, transverse cracks as wide as 1 inch (25 mm) were detected on each abutment wall at four locations. Granular backfill soil was infiltrating into the culvert through the cracks. Secondly, the top slab had two regions where a 2 to 3 inch (51 to 76 mm) thick layer of concrete delaminated exposing the first layer of rebars. The pavement surface above the culvert had numerous hairline cracks and small potholes.

The culvert structure MAD-29-11.37 (4’ x 4’ or 1.22 m x 1.22 m cast-in-place concrete box) served more as a flood control. No drainage flow was flowing through the culvert during the inspection. Deteriorated material conditions, mainly due to salt applications in the winter time, were observed on the headwalls, the wingwalls, and the top slab. However, no exposed rebars were detected in any of the regions.

Headwalls at the site of MAD-142-4.30 (4’ x 3’ or 1.22 m x 0.91 m cast-in-place concrete box) were also showing signs of severe material deteriorations through cracking and softening (due to winter deicing operations). Deterioration/softening of concrete was also observed on the bottom slab. The top slab had a large area near the middle length where material deterioration (softening) had taken place and scaling had made a 1-inch (25-mm) deep cavity into the concrete, as seen in Figure 6.4. The bottom layer of rebars were exposed and heavily rusted in the area. A moderate degree of soil erosion was noted on the embankment slope behind the headwall at the southeast end of the structure.

Figure 6.4: Top Slab of MAD-142-4.30

The aged culvert FAY-753-2.09 (7’ x 5.67’ or 2.13 m x 1.73 m cast-in-place concrete box) had many problems. The mitered ends of the culvert had a few major horizontal cracks on each side. Two major transverse shear cracks were detected inside the culvert (located 9.5 and 14.5 ft, or 2.90 and 4.42 m, away from the outlet end), separating the culvert into three sections. The top slab had a 6-inch (152-mm) deep cavity spanning across the entire width in the mid-length region. Rusted rebars were seen inside the depression. The top slab had a 12-inch (305-mm) length section missing over the entire width at the outlet end. Despite all the cracks, no signs of backfill infiltration were seen inside the culvert. The bottom slab concrete was showing moderate degree of spalling. A 5-inch (127-mm) scour was found in front of the inlet end. At the outlet end, the stream bed was 28 inches (711 mm) lower than the culvert bottom slab surface. No concrete headwalls existed at the site. Instead, flag stones were stacked up next to the culvert end.

The culvert PIK-335-5.18 (14' x 6.67' or 4.27 m x 2.03 m cast-in-place concrete slab-on-top) had a slightly arched top slab and consisted of three sections joined together. Iron-stained transverse cracks were detected near each joint, delaminating the concrete to the first layer of rebars. Minor seepage infiltration was observed at both construction joints.

At the site of CLI-28-7.84 (8' or 2.44 m span cast-in-place concrete slab-on-top), several mid-size areas of concrete deteriorations (3 to 4-inch, or 76 to 102 mm, deep scaled cavity, rusted rebars exposed) were detected on the top slab. Gouges at least 6 to 10 inches (152 to 254 mm) deep existed in the lower portion, just above the flow line level, of the abutment wall (see Figure 6.5). There was one transverse crack across the entire pavement width, located 3 to 4 ft (0.91 to 1.22 m) away from the western edge of the culvert.

The culvert BUT-126-2.58 (8' or 2.44 m-span cast-in-place concrete slab-on-top) had three distinct sections tied in together. The inlet and outlet ends were both cast in-place concrete structures. The main barrel was an older section where the abutment walls were constructed of mortared stones. Concrete was cracked and soft (with rebars exposed) at the edge of the top slab at the inlet end. Mild degree of spalling was seen in the lower area of the headwalls. Each joint between the concrete section and the older masonry section was cracked (crack width 1/10 to 1/4" or 3 to 6 mm).

Figure 6.5: Deteriorated Lower Section of Abutment Wall (CLI-28-7.84)

Horizontal cracks were observed running through the wall just above the normal flow line. There was a 2.5-inch (64-mm) differential settlement between them near the inlet and 1-inch (25-mm) differential settlement near the outlet. Obviously, the main barrel section had settled more than the end sections. The stone walls in the main barrel were not vertical. On each wall, the mortar had been totally lost between the stones at several locations. This created a deep hole as large as 1 inch (25 mm) in diameter at each location. The top slab had several cracks (width up to 1/10" or 3 mm) under the roadway. At the joint between the concrete and masonry sections near the inlet, a 3-inch (76-mm) wide piece of concrete had scaled off. However, there were no signs of backfill infiltration into the culvert. The roadway surface looked relatively new and free of any defects.

The culvert GRE-380-4.97 (2.5' or 0.76 m diameter RCP) consisted of eleven sections joined together. Signs of minor spalling were visible on the lower portion of the pipe sections near the inlet. Circumferential cracks were detected within the bell end section at several joint locations. Joint offset was typically about ½" (13 mm). The pipeline appeared to have a mild degree of sagging in the middle. No headwall structures existed at the site.

The culvert HIG-124-25.75 (6.25'x 4' or 1.91 m x 1.22 m concrete horizontal ellipse) consisted of nine standard 6-ft (1.83-m) length sections. A portion of the culvert outlet end was showing signs of concrete softening. The roadway surface looked relatively new and free of any defects.

The culvert HOC-216-1.99 (9' x 7' or 2.74 m x 2.13 m cast-in-place concrete box) had a few problems. The area of its headwall above the outlet end was fractured and soft. The top slab near the inlet end had a region where the concrete delaminated and exposed rebars over an area 2 ft x 6 ft (0.61 m x 1.83 m). The sediment had accumulated inside the culvert, limiting the head space to only about 4 ft (1.22 m) and the surface drainage flows only on one side.

The headwalls of HOC-78-1.05 (6' x 4' or 1.83 m x 1.22 m cast-in-place concrete box) had deteriorated so severely that more than a half of the initial headwall was missing and three rows of rebars were suspending in the air (see Figure 6.6). Inside the culvert, a few shear cracks were visible on the side walls. And, the bottom slab had a moderate degree of spalling affecting its surface.

Some longitudinal hairline cracks were observed on the top slab in the inlet section of HOC-216-3.25 (4' x 3' or 1.22 m x 0.91 m cast-in-place concrete box). There were a few locations on the top slab where the concrete scaled over a small area. The bottom slab was affected by moderate degree of spalling. The roadway surface was free of any defects.

Figure 6.6: Deteriorated Headwall at Inlet of HOC-78-1.05

A comprehensive culvert inspection was not possible at the site of HOC-216-3.43 (5' x 3' or 1.52 m x 0.91 m cast-in-place concrete box), because the sediment accumulation left only the top 1.5-ft (0.46-m) section of the culvert visible. The top slab at the outlet end was showing signs of severe material deterioration (numerous cracking, softening). Rebars were exposed, and the concrete broke off in pieces easily when stricken by a pick. No headwalls and guardrails existed at the site.

At the site of MRG-78-11.34 (8' x 6' or 2.44 m x 1.83 m cast-in-place concrete box), a 10-inch (0.25-m) deep scour hole was present in front of the inlet end. Inside this culvert, transverse shear cracks were detected running through the abutment walls and the top slab at two locations. Locations of these transverse cracks appeared to define the width of the traffic lanes. Along the crack, shallow scaling problems existed at isolated located. No guardrails were seen at this site.

No direct entry inspection of the culvert was possible at the site of MRG-78-24.97 (2.5' x 2.5' or 0.76 m x 0.76 m cast-in-place concrete box), due to its small size and the fact that a 4.5-inch (114-mm) diameter natural gas pipeline, elevated 12 inches (0.31 m) above the bottom slab, was running through the culvert. Many large boulders were seen lodged underneath the pipeline inside the culvert. The top slab had numerous cracks and moderate to severe material deteriorations. At some isolated locations, the top slab concrete developed ½-inch (13-mm) deep scaled hole, exposing rusted rebars. The headwall/wingwall at the outlet end was in an advanced stage of material deterioration. The concrete was heavily cracked, very soft, exposing internal rebars, and missing a large portion. There was a 2.5-ft (0.76-m) drop from the culvert invert to the stream bed at the outlet end. The embankment slope on the outlet side was steep and showing signs of local slope stability problem.

The culvert VIN-56-6.85 (8' x 6' or 2.44 m x 1.83 m cast-in-place concrete box) was silted up to the point that only the upper 3.5-ft (1.07-m) section was accessible to inspection. The inlet section of the culvert had moderate spalling and scaling on the top slab, exposing the first layer of rebars at one isolated location. The headwall/wingwall assembly showed signs of material deterioration at both ends. At the inlet end, the joint between the wall and the culvert end was open and exposing steel angle placed inside. Also, there was a piece of concrete missing on the west side. At the outlet end, the concrete in the headboard was cracked extensively, soft, and exposing rusted rebars all across its width. Moderate degree of erosion was taking place behind the wingwall on one side at the inlet end.

The culvert MEG-338-16.42 (4' x 4' or 1.22 m x 1.22 m cast-in-place concrete box) broke into four sections by developing transverse shear cracks at 23.5 ft (7.16 m) (1^{st} location) away from the inlet end, 42 ft (12.80 m) (2^{nd} location) away from the inlet end, and 10 ft (3.05 m) away (3^{rd} location) from outlet end. The crack width was up to 2 inches (51 mm) at the first location, up to 3 inches (76 mm) at the second location, and up to ½ inches (13 mm) at the third location. At the first location, seepage infiltration was noted. At the second location, a void space, extending 13 inches (0.33 m) into the adjacent soil fill, was visible through the 3-inch (76-mm) wide crack. At the third sheared location, a 1.5-inch (38-mm) differential settlement was measured between the two sides of the crack. Moderate to severe erosion was detected behind the wingwalls. The stream bed dropped off 12 inches (0.31 m) at the inlet end and more than 3 ft (0.91 m) at the outlet end.

An aged metal culvert was listed for location ATH-278-0.25. Instead, a 7.5' x 4.83' or 2.29 m x 1.47 m concrete horizontal ellipse culvert was found at the site. According to ODOT, the culvert was installed in 2002, while repaving the roadway. This culvert consisted of eight sections joined together. Joint offset was typically ¾ to 1 inches (19 to 25 mm).

The culvert MRG-60-19.95 (4' x 6' or 1.22 m x 1.83 m cast-in-place concrete box) was installed to handle drainage from the hill side during rainfall events. So, it normally had no water flowing through it during dry periods. The culvert had an 11-ft (3.35-m) long extension on the outlet side. The edge of the top slab at the inlet had deteriorated to the point that it had nothing but rusted rebars. The upper half of the headwall was also showing signs of severe material deterioration. The concrete wall surface was rough with numerous hairline cracks and very soft. Inside the culvert, the top slab had some hairline cracks and minor scaling but was still solid. The lower part of the abutment walls and the bottom slab surface had moderate spalling with its surface rough and aggregates being exposed. At the joint between the original section and extension section, there were a few small areas on the top slab where the concrete had scaled and the rebars were exposed. The area behind the headwall at the outlet end had moderate erosion problem. Above the inlet end, the edge of the asphalt pavement layer was cracked and falling.

The culvert CUY-480-0.75 (7' or 2.13 m diameter RCP) showed signs of minor spalling near the flow line elevation throughout its length. Hairline cracks were occasionally seen running either circumferentially or diagonally in the crown region. There were some medium sized (1' x 1' to 2' x 3' or 0.3 m x 0.3 m to 0.6 m x 0.6 m) areas where the thin layer of concrete delaminated over the rebars through scaling. At two locations, small diameter corrugated metal drain pipes connected to the culvert in the shoulder region. Concrete had become fractured and soft at each of these junctions. At the outlet end, the invert had 80% of the concrete gone and all the rebars exposed due to severe material deteriorations.

The culvert CUY-422-15.2 (4' or 1.22 m diameter RCP) appeared to be a relatively new installation. The concrete surface had no hairline cracks and showed little material deterioration. The pipeline consisted of twenty-two standard 8-ft (2.44-m) length sections joined together. The roadway surface looked relatively new and free of any defects.

6.2.3 Conditions Detected at Metal Culvert Sites

During the field inspection program, some specific conditions were observed at the metal culvert sites. Table 6.6 lists these specific fiend conditions encountered, and Table 6.7 shows the type of conditions that existed at each metal culvert site. By far the largest variety of field conditions was detected among the metal culverts compared to the concrete or thermoplastic culverts.

Table 6.6: List of Field Conditions Detected at Metal Culvert Sites

No.	Description of Condition
01	Perforation holes are detected over the invert.
02	Scouring problem exists underneath the culvert.
03	Perforation holes are present at the normal flow line (or at the springline).
04	Inlet section of the culvert is damaged from moving debris.
05	Bolts and plate edges are rusted severely at seams within the top arc.
06	Seam opening (gap between the overlapping plates) wider than ¼ in (6 mm) is detected at seams in the shoulder region.
07	At least one severely rusted pinhole is found on the metal plate. Seepage flow is infiltrating through the hole.
08	The culvert is experiencing moderate deflections ($\geq$ 10%).
09	The main barrel of the culvert is visibly sagging.
10	The top arc is flattened.
11	Reversal of curvature is shown within the top arc.
12	Localized bulges are detected between the shoulder and haunch regions.
13	Bituminous coat has delaminated over a large area of the culvert interior surface.
14	The invert pavement is showing moderate to severe material deterioration.
15	A moderate to large scour hole exists in front of the inlet or outlet end.
16	Severe deterioration of the concrete is detected on the headwall. Rebars are exposed.
17	The headwall either partially or totally failed.
18	Moderate to severe erosion problem is detected behind/around the headwall.
19	The embankment slope is showing signs of slope stability problem. The slope instability is affecting the guardrail and/or pavement.
20	Piping hole is discovered over the culvert.
21	The pavement has transverse cracks running all the way through in the direction parallel to the culvert.
23	Seepage water infiltrates into the culvert.
24	Scouring is detected under the channel concrete lining.
25	The headwall has moved or rotated away from the embankment.
26	The headwall has a major crack running through it.
27	The plates are moderately rusted and becoming soft over the invert.
28	The culvert is supported by a wooden bracing inside.

[Note] Characteristic conditions number listed in this table are used in Table 6.7.

Table 6.7: Existence of Characteristic Conditions at Metal Culvert Sites

Dist.	Culvert I.D.	Characteristic Condition No.:													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
01	PAU-66-2.44			●										●	
01	DEF-18-20.60								●	●				●	
01	PUT-15-14.78			●											
05	LIC-16-13.66			●		●	●	●			●				
05	GUE-70-8.94								●						
05	MUS-93-1.76						●				●	●			
05	GUE-77-7.85R			●					●		●				
05	KNO-95-0.08			●					●						
06	MAD-29-8.80			●											
08	CLI-124-0.03			●											
09	HIG-50-19.82														
09	JAC-124-17.12	●		●									●		●
09	PIK-32-15.96														
09	ADA-247-11.87										●				
10	HOC-595-2.85	●	●												
10	HOC-664-17.16									●					
10	HOC-664-22.40	●	●		●				●		●		●		
10	GAL-7-21.30	●	●						●	●			●		
10	MEG-681-7.94				●									●	●
10	MEG-681-13.96	●													
10	HOC-595-4.57	●	●											●	
10	WAS-339-15.25			●										●	
10	WAS-60-4.84	●					●				●				
12	LAK-90-14.00														
12	LAK-90-4.20														

[Note] See Table 6.6 for descriptions of each characteristic condition.

Table 6.7: Existence of Characteristic Conditions at Metal Culvert Sites (cont'd)

Dist.	Culvert I.D.	Characteristic Condition No.:													
		15	16	17	18	19	20	21	22	23	24	25	26	27	28
01	PAU-66-2.44									●					
01	DEF-18-20.60														
01	PUT-15-14.78		●	●								●	●		
05	LIC-16-13.66	●								●		●			
05	GUE-70-8.94	●												●	
05	MUS-93-1.76													●	
05	GUE-77-7.85R								●		●				
05	KNO-95-0.08								●						
06	MAD-29-8.80	●	●			●							●	●	
08	CLI-124-0.03								●					●	
09	HIG-50-19.82					●									●
09	JAC-124-17.12	●		●										●	●
09	PIK-32-15.96	●						●							
09	ADA-247-11.87							●							
10	HOC-595-2.85	●	●	●	●			●				●	●	●	
10	HOC-664-17.16	●	●									●	●		
10	HOC-664-22.40	●	●	●								●	●	●	

[Note] See Table 6.6 for descriptions of each characteristic condition.

Table 6.7: Existence of Characteristic Conditions at Metal Culvert Sites (cont'd)

Dist.	Culvert I.D.	Characteristic Condition No.:													
		15	16	17	18	19	20	21	22	23	24	25	26	27	28
10	GAL-7-21.30						●								
10	MEG-681-7.94														
10	MEG-681-13.96									●	●				
10	HOC-595-4.57														
10	WAS-339-15.25				●	●									
10	WAS-60-4.84				●							●		●	
12	LAK-90-14.00			●	●							●	●		
12	LAK-90-4.20				●						●	●			

[Note] See Table 6.6 for descriptions of each characteristic condition.

Frequencies of the specific conditions cited at the metal culvert sites are summarized in Table 6.8. Condition Nos. 1 (perforated invert), 3 (perforations at flow line), 15 (scour hole at inlet or outlet), 25 (headwall movement), and 27 (rusted and soft invert plates) were detected somewhat more frequently than the other conditions. In contrast, Condition Nos. 5 (severe rusting at seams), 7 (pinholes in top arc), 11 (reversal of curvature), and 20 (piping holes over culvert) were encountered the least frequently.

Table 6.8: Frequency of Conditions Detected at Metal Culvert Sites

Condition	Frequency	%	Condition	Frequency	%
1	7 (out of 25)	28	15	8 (out of 25)	32
2	4 (out of 25)	16	16	5 (out of 25)	20
3	9 (out of 25)	36	17	5 (out of 25)	20
4	2 (out of 25)	8	18	5 (out of 25)	20
5	1 (out of 25)	4	19	3 (out of 25)	12
6	3 (out of 25)	12	20	1 (out of 25)	4
7	1 (out of 25)	4	21	3 (out of 25)	12
8	6 (out of 25)	24	22	3 (out of 25)	12
9	3 (out of 25)	12	23	3 (out of 25)	12
10	6 (out of 25)	24	24	3 (out of 25)	12
11	1 (out of 25)	4	25	8 (out of 25)	32
12	3 (out of 25)	12	26	6 (out of 25)	24
13	5 (out of 25)	20	27	8 (out of 25)	32
14	2 (out of 25)	8	28	2 (out of 25)	8

The followings are more detailed descriptions of the conditions encountered at each of the twenty-five metal culvert sites.

The twin pipes PAU-66-2.44 (4.5' or 1.37 m diameter twin metal pipes) are scheduled to be replaced in 2006. The pipes were both 64.8 ft (19.8 m) in length and consisted of bolted corrugated plates of size 2.75" (70 mm) pitch x 0.5" (13 mm) depth (thickness 0.116" or 3 mm). The pipes had bituminous coating applied fully inside. Initial walk-through of the two pipes indicated very similar conditions inside the two pipes. The bituminous coat was still intact in the crown region. The coat had been largely removed below the shoulders. Rusting of the steel plates was light above the springline and moderate below the springline. The inlet and outlet sections had at least a few small perforation holes scattered near the normal flow line level. No perforation holes were detected within the main barrel section. Inside diameter measurements taken at a few different stations showed that maximum vertical deflection of 8% existed at the mid-length. The pipes had a slight sag in the middle. A sign of water infiltration was observed at a few seams. There were concrete headwalls constructed at the ends. Instead, at each end the embankment slope enveloping the two pipe ends was concreted. The concrete slope protection looked good on the inlet side. The one at the outlet had a few major cracks. The roadway surface looked relatively new and free of any major defects. There were no guardrails at this site.

The culvert DEF-18-20.6 (6' x 3.67' or 1.83 m x 1.12 m metal pipe-arch) consisted of 2.75" (70 mm) pitch by 0.5" (13 mm) depth corrugated plates (thickness

0.159” or 4 mm) bolted together. This culvert is also scheduled for replacement in 2005. It appeared that initially the plates had been covered with bituminous coat. The bituminous coat was still intact in the crown region. The coat had been largely removed below the shoulders. The plates had moderate degree of rusting especially below the shoulder area. No perforation holes were visible within the top arc and sides. The invert was under a thick silty sediment deposit and could not be inspected. The culvert appeared to have a mild sag in the middle. Tape measurements taken inside the culvert indicated that the vertical deflection might be between 10-14%. There were no concrete headwalls installed at the ends. The culvert ends were metered to conform to the embankment slope.

The culvert PUT-15-14.78 (8’ or 2.44 m diameter metal pipe) consisted of 6” (152 mm) pitch by 2” (51 mm) depth corrugated plates (thickness 0.139” or 4 mm) bolted together at seams. No protective coating had been applied to the plate surfaces. Measurements taken inside the culvert detected only small (less than 2-3%) deflections. Metal plates in the top arc had occasional light corrosion. There were many medium size (2” x 3” or 51 mm x 76 mm) perforation holes on the corrugation crests just below the normal flow line. The headwall at the inlet had numerous hairline cracks, missing a small portion on the left side. The headwall at the outlet had a major horizontal crack as well as numerous hairline cracks. It appeared that the upper half of the wall had moved away from the embankment. At the outlet, the stream bed was 7 ft (2.13 m) lower than the pipe invert. The pavement was resurfaced recently and looked very good. This culvert is scheduled for replacement in 2005.

The culvert LIC-16-13.66 (6.3' or 1.92 m diameter metal pipe) had 3 to 4-inch (76 to 102-mm) diameter perforation holes in the right haunch area, close to the air/water interface, at isolated locations. It was not possible to inspect the invert section because of sediment accumulation. At 33 ft (10.1 m) away from the outlet, seepage water was squirting out through a couple of pinholes located at the right haunch (as shown in Figure 6.7). The top arc was relatively flat over the length of the culvert positioned under the maximum fill height. No stress cracks were detected at bolt lines. Moderate rusting of plates and bolts was observed along seams near the outlet end. The stream bed was significantly lower than the culvert invert at the outlet. The headwall at the inlet was showing damage received from moving debris on the front side and erosion taking place behind. The headwall at the outlet looked rotated. Also, the concrete face below the invert exhibited spalling/flaking.

Figure 6.7: Seepage Water Flowing In Through Pinhole (LIC-16-13.66)

The corrugated plates as well as bolts/nuts in the invert area of the culvert GUE-70-8.94 (5' or 1.52 m diameter metal pipe) were moderately rusted and flaking off in thin layers at many locations. No perforation holes were detected. The metal plates in the other areas (top, sides) were hardly rusted. No seam opening wider than 1/8 inches (3 mm) was observed inside. The culvert's cross-sectional shape looked symmetrical, but the vertical deflection was more than 10% in the middle section. The culvert appeared to be sagging in the middle. The headwall at the outlet end was solid but showed signs of minor material deterioration. There was a 18-inch (0.46-m) deep scour at the outlet. The headwall at the inlet looked newer and in better conditions.

The culvert MUS-93-1.76 (8' or 2.44 m diameter metal pipe) was under a fill height of 64 ft (19.5 m). It had a 28-ft (8.53-m) long, seamless, extension section (corrugation 3-inch or 76 mm pitch x 1-inch or 25 mm depth) added to the original structure through a large concrete box. The plates in the original structure had the standard corrugation size of 6-inch (152-mm) pitch by 2-inch (51-mm) depth. The most noticeable condition inside the original structure was the flattening of the left shoulder area (looking upstream) in the section under the maximum fill height. The top left mid-ordinate measurement was 2 inches (51 mm) less than the top right mid-ordinate measurement. A slight reversal of curvature was showing up in the area. The culvert's cross-section was definitely not symmetric. Seam opening in the left shoulder area was up to ½ inches (13 mm) in the mid-length section. No signs of backfill infiltration were observed. The maximum vertical deflection was 8.3%. The invert plates were rusted moderately (flaking off in thin layers at many locations), but no perforation holes existed through the plates. The plates in the top, side, and corner regions were not rusted. The stream bed in front of the inlet end was 2 ft (0.61 m) lower.

The culvert GUE-77-7.85R (6' or 1.83 m diameter metal pipe) was under a 40-ft (12.2-m) soil cover. Several small (2"-3" or 51-76 mm diameter) perforation holes were detected in the springline region in the inlet section. A small amount of backfill soil was infiltrating through one of the holes. Small perforation holes continued to exist at the springline at isolated places throughout the structure. In addition, larger perforation holes were found at the 5:00 o'clock position at a few locations (34.5' and 6', or 10.5 and 1.8 m, away from the outlet end). The invert plates were buried under sediment. The plates above the springline were rusted only surficially along the edges and on the bolts. Moderate degree of rusting and flaking was observed on the plates at the 9:00 o'clock position (left springline), 10.5' (3.2 m) away from the inlet end. The vertical deflection taken at the mid-length was about 5%. However, the vertical deflection taken further downstream (126' or 38.4 m from the outlet end) was 11.8%. Slight flattening of the top and bottom arcs was noticed in this area. The headwall at the inlet had only minor material deteriorations. However, its lower right corner was cracked. The headwall at the outlet had several hairline cracks above the crown. The stream bed was lined with concrete at the outlet. The concrete liner was broken into many pieces (see Figure 6.8).

Figure 6.8: Deteriorated Concrete Liner at Outlet of GUE-77-7.85R

The culvert KNO-95-0.08 (4’ or 1.22 m diameter metal pipe) normally carried no drainage flow and served as a flood control device. The culvert consisted of three seamless 20-ft (6.1-m) length pipe sections. The corrugated plates had a size of 3” (76 mm) pitch by 0.5” (13 mm) depth and a thickness of 0.111” (3 mm). The metal plate was heavily rusted and perforated at 4:00 and 8:00 o’clock positions, as shown in Figure 6.9. The invert section was not visible for direct inspection, being covered under 6-inch (152-mm) deep sediment. Inside measurements taken at several locations found a maximum vertical deflection of 18% at Joint 2 (20 ft or 6.1 m away from the inlet end). The culvert shape appeared to be somewhat nonsymmetrical. At the crown of Joint 1 (20 ft or 6.1 m away from the outlet end), a 2-inch (51-mm) gap existed between the two pipe ends, exposing granular soil. The culvert had no concrete headwalls at the ends.

Figure 6.9: Perforations at Flow Line Inside KNO-95-0.08

The inlet-end headwall of the culvert MAD-29-8.80 (7' or 2.13 m diameter metal pipe) had deteriorated severely (numerous cracks, concrete softening) from years of roadway salt applications. A few elongated small size (2-3" or 51-76 mm width x 3-4" or 76-102 mm length) perforation holes were present on the invert plates on both sides at the normal flow line not too far from the inlet end. A larger perforation hole (3" or 76 mm width x 1.5' or 457 mm length) was also detected at the flow line near the outlet end. No perforations were detected above or below the normal flow line. The culvert had only slight deflections. The pavement surface above the culvert looked good. The guardrail on the outlet end side was curved, moving away from the roadway due to a slope stability problem. The asphalt pavement had tension cracks in the area as well (see Figure 6.10). The embankment slope below the affected guardrail was steep and covered with large riprap stones. The headwall at the outlet had a major vertical crack and a small gap running through it. The stream bed dropped 3 ft (0.91 m) at the outlet end.

The culvert CLI-124-0.03 (9.5’ x 6.42’ or 2.90 m x 1.96 m metal pipe-arch), consisting of 0.148” (4 mm) thick corrugated plates of 6” (152 mm) pitch x 2” (51 mm) depth, was serving under a 5.5 ft (1.68 m) cover. There was no protective coating applied to the culvert plates. Metal plate surface looked only slightly rusted in the top arc along the culvert length, except in a 15-ft (4.57-m) section located 15 to 30 ft (4.57 to 9.14 m) away from the outlet end. Here, the metal plates and bolts were both heavily corroded on the invert and the left shoulder. Scattered perforations of typical size 2” (51 mm) width by 12” (305 mm) length were detected mostly at the flow line level of the invert plates.

Figure 6.10: Tension Cracks along Edge of Pavement (MAD-29-8.80)

On the left shoulder, an elongated hole of size 1” (25 mm) width by 18” (457 mm) length was detected 30 ft (9.14 m) away from the outlet end (shown in Figure 6.11). Gray, cohesive backfill soil was visible through the hole. No sizable void space had developed outside the perforated hole. The invert plates were moderately rusted and somewhat soft in the inlet area. The culvert had a symmetric shape and only slight deflections (vertical deflection 4%). The bolted seams looked tight. There was a 12-inch (0.31-m) deep scour at the inlet. The stream bed at the outlet was concreted. Headwalls looked like they had only slight material deteriorations.

Figure 6.11: Elongated Perforation Holes Detected at Left Shoulder (CLI-124-0.03)

The culvert HIG-50-19.82 (6’ or 1.83 m diameter metal pipe) had a wooden bracing structure erected inside for reinforcement. The pipe was serving under a 5-ft

(1.52-m) cover. The pipe consisted of seamless sections joined together. The plate thickness was 0.16" (4 mm), and its pitch and depth were 2.75" (70 mm) and 5/8" (16 mm). The invert area was rusted only on the surface. The culvert deflections were relatively small. The embankment slopes were steep and covered with ODOT Type D riprap rocks. It appeared that there had been a minor slope movement especially on the outlet side. The guardrail had a deflection over two posts, and the pavement edge had tension cracks. The west bound lane of Rt. 50 over the culvert had an asphalt patch over it. There were no concrete headwalls at this site.

The culvert JAC-124-17.12 (7.25' x 5.25' or 2.21 m x 1.60 m metal pipe-arch) was under only 2.5 ft (0.76 m) of cover. It had invert paving and was supported by timber braces, as seen in Figure 6.12. The invert pavement had an area, about 10 ft (3.1 m) away from the outlet end, where the top 2-inch (51-mm) of concrete had eroded and exposed some rusted rebars. The culvert consisted of three distinctive sections -- a 5-ft (1.52-m) long seamless pipe at the inlet, a 15-ft (4.57-m) long multi-plate pipe-arch section in the main barrel, and a 35-ft (10.67-m) seamless pipe section to the outlet. This arrangement indicated that the original pipe-arch structure had been partially replaced in the past. The corrugation size was 3" (76 mm) pitch by 1" (25 mm) depth through all three sections. The metal plates were rusted on the invert. A few small perforation holes were visible just above the concrete invert pavement. A 6" (152 mm) inward bulge was found at 10:30 clock position, 9 ft (2.74 m) away from the inlet (in the older pipe-arch section). The horizontal alignment of the culvert was not straight, due to the presence of the three sections. The concrete headwall at the inlet end had deteriorated to the point that it was nearly gone. There was no concrete headwall at the outlet end. There was a 13.5” (0.34 m) deep scour hole at the outlet. The pavement surface above the culvert had two major (wider than 0.1” or 3 mm) transverse cracks running in parallel to the culvert structure, as seen in Figure 6.13. The cracks appeared to be related to the culvert performance. There was no noticeable dip on the pavement surface.

Figure 6.12: Timber Bracing Applied Inside JAC-124-17.12

Figure 6.13: Transverse Crack Detected Above JAC-124-17.12

The culvert PIK-32-15.96 (7' or 2.13 m diameter metal pipe) was 391 ft (119.2 m) long and was serving under a 16 ft (4.88 m) of soil fill. Its corrugation plates had a rare size of 5" (127 mm) pitch by 1" (25 mm) depth with a thickness of 0.108" (3 mm). No protective coating layer was applied to the culvert interior. However, a concrete invert pavement existed along the culvert length. Conditions of the invert pavement layer were good. The corrugated plates had minor dents and bulges at numerous locations. These were most likely induced during construction. The culvert was experiencing only small deflections (max. vertical deflection 4%). The headwall at each end looked good with only a minor hairline crack running vertically above the crown. There was a 6-ft (1.83-m) deep scour hole at the outlet end (see Figure 6.14).

Figure 6.14: A Large Scour Hole at Outlet of PIK-32-15.96

The twin pipes ADA-247-11.87 (4’ or 1.22 m diameter twin metal pipes) were both 51 ft (15.5 m) long and consisted of non-sectional corrugated steel plate of size 2.625” (67 mm) pitch x 0.5” (13 mm) depth. Each pipe consisted of three sections:

Inlet Section	(Length 6’ or 1.83 m; Wall Thickness 0.057” or 1.5 mm)
Main Barrel Section	(Length 39’ or 11.89 m; Wall Thickness 0.108” or 3 mm)
Outlet Section	(Length 6’ or 1.83 m; Wall Thickness 0.057” or 1.5 mm)

No protective coat was applied to the pipes. Initial walk-through of the two pipes indicated that the “south” pipe had somewhat worse conditions. Because of the thin wall thickness, the inlet end section of each pipe had a significant flattening at shoulder locations. The diameter measurements taken inside the pipes showed only up to 2% vertical and horizontal deflections. Each pipe had a slight sag in the middle. The steel plate was mildly rusted in the crown and invert regions inside both pipes. No perforation holes were detected in either pipe. There were no concrete headwalls erected at the ends.

Instead, 3-4 inch (76-102 mm) diameter riprap stones were dumped over the embankment slopes around each end. Examination of the roadway surface revealed a transverse crack running along the north pipe.

The culvert HOC-595-2.85 (7.67' x 5.42' or 2.34 m x 1.65 m metal pipe-arch), installed in 1951, was 52 ft (15.85 m) in length. Its corrugated plates had a pitch of 6 inches (152 mm), a depth of 2 inches (51 mm), and a thickness of 0.182 inches (5 mm). The height of cover over the culvert was only 12 inches (0.31 m). This was actually the first culvert structure inspected in the current research project. There were a few serious problems associated with this culvert. Inside dimensions taken at the mid-length section were – rise 63.0" (1.60 m), span 91.0" (2.31 m), left span 46.75" (1.19 m), top mid-ordinate 39.75" (1.0 m), top left chord 60.5" (1.54 m), top right chord 60.0" (1.52 m), top left mid-ordinate 11.0" (0.28 m), and top right mid-ordinate 11.75" (0.30 m). These dimensions indicated that the culvert had only small deflections and distortions (the shape was not a problem). The horizontal alignment of the culvert looked good, but the structure appeared to have a minor sag in the middle. A survey of general culvert material conditions revealed light corrosion existed at isolated locations over the top, side, and corner regions. A location of moderate rusting was detected at the crown 5 to 10 ft (1.52 to 3.05 m) away from the outlet. The seams in the upper arc looked tight. The metal plates on the invert were more heavily rusted and perforated extensively. The deteriorated conditions of the invert plates became worse toward the outlet end. The bedding was washed out under the culvert from the outlet end to about 13 ft (3.96 m) away from the outlet end (see Figures 6.15 and 6.16). The headwall at the inlet was cracked and tilted away from the embankment. Also, severe erosion was detected behind the inlet headwall on one side. The headwall at the outlet end had no concrete under the culvert (sheared off), as shown in Figure 6.16. Level survey conducted across the pavement surface picked up a minor dip of the surface. Two transverse cracks were running across the pavement width in the direction parallel to the culvert. There were no guardrails installed.

Figure 6.15: A Large Void Space Under HOC-595-2.85

Figure 6.16: Shear Failure of Outlet Headwall at HOC-595-2.85

The culvert HOC-664-17.16 (8.6’ x 5.9’ or 2.62 m x 1.80 m metal pipe-arch) was installed in 1959 and received no repairs/modifications over the years. It was constructed with sectional plates having a 6-inch (152-mm) pitch, 2-inch (51-mm) depth, and 0.20-inch (5-mm) thickness. The culvert was skewed at 45˚, and its 66-ft (20.1-m) length was under 1 to 1.5 ft (0.31 to 0.46 m) of cover. No protective coating was applied to the plates inside. The invert section of the culvert was buried under up to 11-inch (0.28 m) deep sediment. The corner plates were moderately rusted in the inlet section. However, no perforation holes or missing bolts were observed in the area. Rise and span measurements taken inside the culvert showed that the structure had experienced only small deflections. The culvert appeared to be experiencing a minor sag in the mid-length section. At a section 13 ft (3.96 m) away from the outlet end, moderately rusted plates and bolts were detected at a seam located in the top region. The headwalls of the culvert exhibited an advanced stage of material deterioration. At the inlet end, the headwall had numerous cracks with a portion of the wall missing. In the right shoulder region, the culvert plate and the headwall concrete were separated by a 1-inch (25-mm) gap. At the outlet end, the conditions of the headwall were even worse. The full-height headwall had no concrete remaining above the culvert, with a rusted rebar completely exposed. Also, the headwall appeared to have rotated away from the roadway embankment. A 12-inch (0.31-m) deep minor scour hole existed at the outlet end. The roadway surface had numerous cracks above the culvert. There were no guardrails at this site.

The culvert HOC-664-22.4 (7' or 2.13 m diameter metal pipe) was 48 years old at the time of field inspection. It was assembled with standard corrugated sectional plates (6-inch or 152-mm pitch x 2-inch or 51-mm depth) and had a total length of 100 ft (30.5 m). The plate thickness was 0.14 in (4 mm). The plates had no protective coating over them. The culvert was under a soil cover of 12 ft (3.66 m). Horizontal and vertical diameters were measured at 10-ft (3.05-m) intervals along the culvert length. The measurements are listed in Table 6.9 below. These measurements indicate that the serious condition existed mostly within the first 20 ft (6.10 m) from the inlet end. The team observed that the culvert section in this area consisted of severely distorted plates, ripped apart at seams. A large seam opening on the invert created a hole where the drainage flow could plunge and scour the bedding soil (see Figure 6.17). According to a local resident, there was a major flood in this area in the past. The inlet headwall and section were damaged under an accumulation of large debris during the flood event. The top arc appeared to be somewhat flat throughout the culvert, except in the last 20 ft or 6.1 m (near the outlet). Also, small bulges were detected at isolated locations.

Table 6.9: Diameter Measurements Taken Inside HOC-664-22.4 Culvert

Distance from Inlet End (ft)	Inside Diameters (inches):		Distance from Inlet End (ft)	Inside Diameters (inches):	
	Vertical	Horizontal		Vertical	Horizontal
10	68	66	60	77.5	86
20	77.5	86	70	76.5	85.3
30	75	84.5	80	82.5	83
40	74.5	78.5	90	83.5	82.5
50	79	85.5	---	---	---

[Note] 1 inch = 25 mm; and 1 ft = 0.305 m.

Figure 6.17: Damaged Inlet Section of HOC-664-22.4

Metal plates above the invert exhibited no corrosion problem. The metal plates in the invert section had moderate corrosion. The invert had some small holes near the outlet end and a medium sized perforation hole at the outlet end. A small remnant of the headwall was found on one side at the inlet. It was clear that the headwall had either totally failed or had been removed at the entrance. The headwall at the outlet was still largely intact. The section underneath the culvert had a portion missing and cracks propagating. The drainage flow was flowing under the invert and impacting the concrete surface. The channel bed was much lower than the invert elevation at the outlet. The roadway surface showed two transverse cracks (width > 0.1" or 3 mm) running across the entire pavement width. Guardrails appeared to be in good service conditions.

The culvert GAL-7-21.3 (2.5' or 0.76 m diameter metal pipe) had an age of 64 years, a length of 108 ft (32.9 m) and a slope of 15%, serving under 6 ft (1.8 m) of cover. According to ODOT, a hole had surfaced in the shoulder section of Rt. 7 above the culvert (on the inlet side) about two years ago. The hole was covered with a thick steel plate as a temporary measure. Inspection of the aged culvert revealed that it consisted of three distinct sections. The section at the inlet was a 28.5-inch (0.72-m) diameter CMP (corrugation pitch 2.5" or 64 mm; corrugation depth 0.5" or 13 mm; thickness 0.1" or 3 mm) with a length of 22 ft (6.71 m). This section had its invert completely rusted out along its entire length. The drainage water was flowing on top of exposed soil, underneath the culvert. The channel above the inlet end was basically a ditch on a steep slope. There were numerous signs of erosion problems along the channel. The full-height concrete headwall at the inlet end was suffering from minor material deteriorations but free from any major cracks or movements. The outlet section was also 22 ft (6.71 m) in length and had the same features as the inlet section. The invert of the outlet section was also rusted away, leaving a 6-inch (152-mm) wide gap at the bottom along the length. Drainage flow was flowing on top of the soil below the culvert and causing erosion. The culvert in the main barrel section had a diameter of 24 inches (0.61 m). It was disjoined from the end sections. The main culvert section appeared to have a very mild slope and was nearly half full of water. It had moderate deflections and a few small bulges on the sides. A medium-size void was developing within the embankment fill at each location of joint opening. The hole in the shoulder area (on the inlet side) was determined to be located immediately above the joint opening between the inlet and main sections. A similar hole was detected above the culvert joint on the outlet side, but this hole surfaced to the embankment slope. A steady stream of drainage water was seeping out on the slope, about 10 ft (3.1 m) away from the culvert outlet end. This offered additional evidence that the soil fill surrounding the culvert was suffering from piping (internal erosion) problems. The culvert was replaced during May-June of 2003. The contractor retained by ODOT performed jack and bore operations next to the existing culvert to install a new 36-inch (0.91-m) diameter CMP (length 78 ft or 23.8 m; slope 7%). The original culvert was filled with grout to cease its function as a drainage structure.

The culvert MEG-681-7.94 (6' or 1.83 m diameter metal pipe) was one of the few culverts with a protective coating as well as invert paving applied to the culvert. The drainage flow was very rapid, and some large debris was located at the inlet end. The invert pavement layer had been largely removed. The bituminous coat was still mostly intact in the top arc section (see Figure 6.18). The culvert plates were moderately rusted in the corner and invert. No perforation holes were detected. Hammering by a pick flaked off the metal in thin layers. The culvert had slight deflections and sagging. No dips were detected on the roadway surface.

The culvert MEG-681-13.96 (7.3’ x 5.3’ or 2.23 m x 1.62 m metal pipe-arch) had several medium size perforation holes on its invert near the inlet end and many small perforations throughout its invert. Seepage water infiltration was noted at a seam in the crown under the roadway centerline. The culvert had slight deflections and sagging.

Figure 6.18: Delaminated Protective Coating Inside MEG-681-7.94

The culvert HOC-595-4.57 (7.3’ x 5.3’ or 2.23 m x 1.62 m metal pipe-arch) had many perforations on the invert despite the fact that it was protected fully with bituminous coating. Two large size (about 3’ x 3’ or 0.91 m x 0.91 m) perforation holes were found on the invert near the inlet end, as shown in Figure 6.19. Because of the extent of perforation in this area, the drainage flow was moving below the invert and causing up to 12-inch (0.31-m) deep scouring under the culvert. Invert plates were heavily rusted at the outlet as well. One 2' x 2' (0.61 m x 0.61 m) perforation hole was discovered on the invert near the outlet end. Invert of the main barrel had small perforations scattered throughout. The drainage water was flowing over the invert in the main barrel section. The bituminous coat was nonexistent over the invert and spotty over the sides and top arc. General shape of the culvert appeared to be good, with vertical deflection only about 3%. The headwall at each end had at least one major crack and showed signs of minor material deterioration.

Figure 6.19: Large Perforation Holes Through Invert of HOC-595-4.57

The culvert WAS-339-15.25 (6' or 1.83 m diameter metal pipe) was under a 6-ft (1.83-m) soil cover. The structural plates were covered with bituminous coating, had size of 6" (152 mm) pitch x 2" (51 mm) depth, and a thickness of 0.167" (4 mm). The protective coat was mostly intact but delaminated at isolated locations within the top arc. The coating was nearly nonexistent in the corner and invert sections. The invert plates were rusted but still relatively solid. There were medium-sized perforation holes at the normal flow line throughout the culvert length. The culvert shape looked good. No stress cracks or seam opening were found inside. The headwall at each end had minor material deteriorations such as spalling and up to ¼" (6 mm) deep scaling. There was a moderate degree of erosion taking place on the embankment slope behind the headwall at the inlet. Five guardrail posts near the outlet end were leaning away from the roadway surface, implying some slope movements over the years. At the outlet end, the stream bed was 12 inches (0.31 m) lower than the culvert invert.

The culvert WAS-60-4.84 (8' or 2.44 m diameter metal pipe) consisted of structural plates characterized by a 6" (152 mm) x 2" (51 mm) corrugation size and a thickness of 0.147" (4 mm). It was serving under a 21 ft (6.4 m) of soil cover. The plates had no protective coating and were rusted extensively in the invert region. The invert plates were relatively soft. Medium size perforations were detected only in the inlet and outlet sections. One side of the inlet headwall was tilted away from the embankment slope. The soil it used to retain had been washed off, exposing the side of the culvert. The headwall at the outlet end looked fine. The culvert shape appeared relatively poor in the main barrel, especially at 32.2 ft (9.8 m) away from the inlet end. Up to a ½" (13 mm) seam opening was detected in the shoulder area. Inside measurements showed that the culvert had a 6% vertical deflection and a 27% reduction in the top mid-ordinate. These measurements indicated that the top arc had become flat.

The culvert LAK-90-14.0 (15' or 4.57 m diameter metal pipe) was the largest size metal culvert inspected in the current study. According to ODOT records, the invert of this culvert was paved with concrete in 2002. The plates in this culvert had a size of 6" (152 mm) pitch by 2" (51 mm) depth (thickness 0.288" or 7 mm). No protective coat had been applied to the plates. The culvert had a total length of 420 ft (128.0 m) and was placed under a 40 ft (12.2 m) cover. The metal plates had only slight discoloration and rusting. The culvert's cross-sectional shape looked round with no areas of flattening. The invert pavement looked good with only occasional hairline cracks and minor dents. No measurable sediment accumulation was recorded due to rapid drainage flow. The concrete headwall at the inlet had minor material deteriorations. In contrast, the headwall at the outlet looked to be rotated away from the embankment by as much as 5˚. A major crack was observed on the concrete wall below the pipe invert. There were some signs of erosion behind this headwall.

The culvert LAK-90-4.2 (10' or 3.1 m diameter metal pipe) was the longest (length 922 ft or 281 m) metal culvert structure in the inspection program. The plates in this culvert had a size of 6" (152 mm) pitch by 2" (51 mm) depth (thickness 0.278" or 7 mm). No protective coat had been applied to the plates. Each culvert end was mitered to conform to the embankment slope. The exposed ends of the culvert had mildly rusted spots. Conditions of this culvert were in many ways similar to those of the culvert LAK-90-14.0. The plate surfaces inside the culvert looked good, except in the section near the outlet end where minor to moderate degree of rusting existed at isolated seams. No perforation holes were found anywhere on the plates. No measurable sediment accumulation was recorded due to rapid drainage flow. The invert pavement looked good with only occasional hairline cracks and minor dents. The concrete headwall at the outlet end looked slightly rotated away from the embankment. A few cracks were found on the headwall in the culvert haunch area. There was sign of soil erosion behind the headwall at the outlet end. Also, a large medium-depth scour hole was present in the stream just below the outlet end. At the inlet end, two concrete-lined ditches carried the surface drainage flow into the concrete apron in front of the culvert inlet. The concrete apron by the inlet end was partially scoured underneath.

6.2.4 Conditions Detected at Thermoplastic Pipe Culvert Sites

During the field inspection program, some specific conditions were observed at the thermoplastic pipe culvert sites. Table 6.10 lists these specific conditions encountered, and Table 6.11 shows the type of conditions that existed at each plastic pipe culvert site. It is noted here that none of the conditions existed at other sites was detected at three thermoplastic culvert sites on Rt. 33 Bypass.

Table 6.10: List of Field Conditions Detected at Thermoplastic Pipe Sites

No.	Description of Condition
01	Vertical deflection is 7.5% or larger.
02	Horizontal deflection is 7.5% or larger.
03	The top arc is relatively flat.
04	The bottom arc is relatively flat.
05	Dimples exist in the region between the shoulder and springline positions, which represent localized buckling of the internal hydraulic liner (applies to HDPE pipes only).
06	Moderate misalignment exists at the joints.
07	Localized bulges are detected between the shoulder and haunch regions near the joint.
08	Interior liner is separated from the structural wall near the joint at isolated locations.
09	Moderate to severe sediment accumulation is detected inside the culvert.
10	A moderate to large scour hole exists in front of the inlet or outlet end.
11	Pavement has transverse cracks running all the way through in the direction parallel to the culvert.
12	The embankment slope is showing signs of slope stability problem.

[Note] Numbers represent the characteristic conditions in Table 6.11.

Table 6.11: Existence of Characteristic Conditions at Thermoplastic Pipe Sites

Dist.	Culvert I.D.	Characteristic Condition No.:											
		1	2	3	4	5	6	7	8	9	10	11	12
05	FAI-33b-Sta. 446+92	●	●	●		●	●	●	●				
05	PER-13-11.14				●	●	●			●	●	●	
05	FAI-33b-Sta. 587+96												
05	FAI-22-Sta. 17+20												
05	FAI-33b-SR18-Sta. 86+00	●	●			●				●			
05	FAI-33b-SR18-Sta. 96+00												
05	FAI-33b-Ramp J (Sta. 488+07)						●						
10	MEG-124-30.17	●				●	●	●				●	●
10	HOC-327-2.70	●	●							●		●	
10	NOB-145-3.59	●	●	●	●								

[Note] See Table 6.10 for descriptions of each characteristic condition.

Deflections measured inside the thermoplastic pipe culverts are listed in Table 6.12. The vertical deflection was less than 10% inside all the thermoplastic pipe culverts. The ratio between the vertical and horizontal deflections varied widely among the ten field sites.

Table 6.12: Measured Deflections of Thermoplastic Pipe Culverts

Dist.	Culvert I.D.	Culvert Description	Deflection: Vertical	Deflection: Horizontal	Note
05	FAI-33b-Sta. 446+92	60” Dia. Corrug. HDPE	- 7.9%	7.9%	Under construction.
05	PER-13-11.14	42” Dia. Corrug. HDPE	- 7.1%	2.4%	--
05	FAI-33b-Sta. 587+96	48” Dia. PVC	- 6.3 %	3.1%	Under construction.
05	FAI-22-Sta. 17+20	36” Dia. PVC	- 2.1%	< 1%	Under construction.
05	FAI-33b-SR18-Sta. 86+00	36” Dia. Corrug. HDPE	- 3% (min.)	NA	Under service road; Under construction.
05	FAI-33b-SR18-Sta. 96+00	36” Dia. PVC	- 2%	< 1%	Under service road; Under construction.
05	FAI-33b-Ramp J (Sta. 488+07)	30” Dia. PVC	< - 1%	< 1%	Under ramp section; Under construction.
10	MEG-124-30.17	48” Dia. HC-HDPE	- 8.5%	2.0%	--
10	HOC-327-2.70	42” Dia. Corrug. HDPE	- 7.1% (min.)	10.7%	--
10	NOB-145-3.59	24” Dia. Corrug. HDPE*	- 8.3%	8.3%	pH = 4.6

* [Note] This pipe had no hydraulic liner inside; 1” = 25 mm.

Frequencies of the specific conditions cited at the thermoplastic pipe culvert sites are summarized in Table 6.13. Condition Nos. 1 (vertical deflection > 7.5%), 2 (horizontal deflection > 7.5%), 5 (local buckling of hydraulic liner), and 6 (misalignment at joint) were detected somewhat more frequently than the other conditions. In contrast, Condition Nos. 8 (separation of hydraulic liner), 10 (scour hole at inlet or outlet), and 12 (embankment slope instability) were encountered the least frequently.

Table 6.13: Frequency of Conditions at Thermoplastic Pipe Culvert Sites

Condition	Frequency	%	Condition	Frequency	%
1	5 (out of 25)	20	7	2 (out of 25)	8
2	4 (out of 25)	16	8	1 (out of 25)	4
3	2 (out of 25)	8	9	3 (out of 25)	12
4	2 (out of 25)	8	10	1 (out of 25)	4
5	4 (out of 25)	16	11	3 (out of 25)	12
6	4 (out of 25)	16	12	1 (out of 25)	4

Detailed descriptions of the conditions encountered at each of the ten thermoplastic pipe culvert sites are presented in the following paragraphs.

According to an ODOT field inspector, a heavy construction equipment ran over the 60-inch (1.52-m) diameter HDPE pipe (FAI-33b-Sta. 446+92) when the height of cover was only 5 ft (1.52 m). As a result, the pipe deflected vertically and developed localized buckling of the internal hydraulic liner in the springline region. This pipe was backfilled with ODOT Item 304 Type 1 (sand). All indications were that the sand backfill was not properly compacted during the installation of this culvert. Therefore, the installation conditions of this pipe represented one of the worst conditions among the thermoplastic culverts inspected in the project.

The 42-inch (1.07-m) diameter HDPE pipe (PER-13-11.14) consisted of three standard length sections, giving it a total length of 60 ft (18.3 m). According to the manufacturer, this pipe product was manufactured by an obsolete process. Minor dimpling of the internal hydraulic lining existed at the springline positions from about 6 ft (1.83 m) inside the inlet end to about 5 ft (1.52 m) away from the outlet end. In the middle section, the bottom arc appeared flat. Cross-sectional shape was like an oval and symmetric. There were no headwalls at the ends. Roadway embankment slopes surrounding the pipe inlet/outlet were treated with ODOT Type "C" rock protection. The roadway surface had two transverse cracks running parallel to the skewed pipeline structure (see Figure 6.20). The cover height over the pipe was only 1.5 ft (0.46 m). A deep scour hole was found below the outlet end.

Figure 6.20: Skewed Transverse Cracks Over PER-13-11.14

The 48-inch (1.22-m) diameter PVC pipe (FAI-33b-Sta. 587+96) had a smooth wall. It consisted of thirteen standard length sections and a short section added next to a manhole (total pipeline length 173.8 ft or 53.0 m). The height of cover was 14 ft (4.3 m) on the day the culvert was inspected. The final construction plan calls for 17 ft (5.2 m) cover. The headwalls, as well as the bottom half of the pipe, were submerged in drainage water. According to the inside diameter measurements, the pipe was experiencing less than 5% deflections. The pipe material visible above the water surface looked new and free from any defects. Figure 6.21 shows a general interior view of this pipe.

Figure 6.21: General View Inside PVC Pipe (FAI-33b-Sta. 587+96)

The 36-inch (0.91-m) diameter PVC pipe (FAI-22-Sta. 17+20) existed under a ramp off U.S. Rt. 22, just west of a bridge constructed over Rt. 33 Bypass. The wall section had a small corrugated design. The pipeline consisted of eight standard length sections (total length 104 ft or 31.7 m). The structure was installed less than one year ago. So, all the conditions looked new and free from any defects. The ramp section was still under construction and had no pavement layer.

At the 36-inch (0.91-m) diameter corrugated HDPE pipe (FAI-33b-SR18-Sta. 86+00) site, it was possible to inspect only the first three sections of the pipeline structure. The culvert did not have a standard straight-out inlet end. The inlet end was tied to a catch basin, and the culvert had more than 12 inches (0.31 m) of sediment accumulated inside. This pipe was backfilled with ODOT Item 304 Type 2 (crushed limestone). At the second joint (from the outlet end), shallow dimples covered the pipe wall surface around the circumference, shown in Figure 6.22. No tearing of the inside hydraulic liner or liner seams was detected.

Figure 6.22: General View Inside HDPE Pipe (FAI-33b-SR18-Sta. 86+00)

The 36-inch (0.91-m) diameter PVC pipe (FAI-33b-SR 18-Sta. 96+00) had corrugated wall design on the outside surface and smooth-walled inside. The pipeline consisted of five standard length sections (total length 59.2 ft or 18.0 m). The culvert was under 2 ft (0.61 m) of soil cover and carried no drainage flow on the day it was inspected. The structure was installed less than one year ago. So, all the conditions looked new and free from any defects. The service road above the culvert was in early stages of construction.

The wall section of the 30-inch (0.76-m) diameter PVC pipe (FAI-33b-Ramp J-Sta. 488+07) had a small corrugated design just like the 36-inch (0.91-m) diameter PVC pipe (FAI-22-Sta. 17+20). The pipeline consisted of seven standard length sections and a 13-ft (3.96-m) length section (total length 153 ft or 46.6 m). The pipeline had mild sagging in the mid-length region. This pipe was backfilled with ODOT Item 304 Type 2 (crushed limestone). The structure was installed less than one year ago. So, all the conditions looked new and free from any defects. The ramp section was still under construction and had no pavement layer.

At the site of MEG-124-30.17, a 48-inch (1.22-m) diameter HDPE pipe (MEG-124-30.17) existed instead of an aging 3' x 4' (0.91 m x 1.22 m) concrete box culvert as reported by ODOT. The wall of the plastic pipe was a honey-comb design. The pipeline consisted of three standard length sections (total length 60 ft or 18.3 m). A sign of minor local buckling of the internal liner was visible at 9:00 o'clock position (while facing upstream) from the mid-length of Section 2 to near the end of Section 3. The top arc appeared to be flattening. The pipe's cross-sectional shape was like a symmetric horizontal ellipse. A minor bulge was detected in the left haunch area, 12 ft (3.66 m) away from the outlet end. The pipeline appeared to have minor misalignment conditions, as uneven distances were observed at each joint around the circumference between the joined pipe ends. A portion of the roadway embankment, approximately 10 ft (3.1 m) to the east of the outlet end, was showing sign of minor slope movement. The pavement surface had no transverse cracks above the culvert.

The 42-inch (1.07-m) diameter corrugated HDPE pipe (HOC-327-2.70) had a smooth lined interior. The pipeline consisted of two standard length sections (total length 40 ft or 12.2 m). According to a local resident, the previous metal culvert structure was washed away during a heavy storm event about one year ago. There were no signs of wall buckling or tearing inside the culvert. There were no concrete headwalls at the ends. Sediment accumulation was about 14 inches (0.36 m) deep at the outlet. The pavement surface had a 5-ft (1.5-m) wide area, over the culvert that had been patched with two layers of asphalt concrete material. There were some transverse cracks extending out of the patched area.

The conditions of the 24-inch (0.61-m) diameter HDPE pipe (NOB-145-3.59) were especially worth noting. This plastic pipe was installed 23 years ago and has been serving under low-pH and abrasive drainage flow, with only 12 inches (0.31 m) of cover. The pipe's cross-sectional shape at the mid-length was like a horizontal ellipse, with vertical deflection at 8.3%. However, no signs of localized wall buckling were detected inside the pipe. The pipe wall surface inside had many shallow scratch marks. However, no puncture holes or tearing were detected anywhere inside the pipe. Figure 6.23 shows a general interior view of this pipe.

Figure 6.23: General View Inside HDPE Pipe (NOB-145-3.59)

Field performance of the plastic pipes installed at the Rt. 33 bypass project in Fairfield County, District 5, was evaluated on two occasions (April 03, April 04) during the current project. No significant deteriorations in their field performance were observed for any of the culverts, while the construction progressed at the site. The highway project will not be completed until 2007.

6.3 BASIC ANALYSIS

This section of Chapter 6 attempts to conduct a basic analysis of the data collected during the field culvert inspection phase. More advanced data analysis will be presented in Chapter 7, where some multi-variable statistical methods are applied to identify important parameters and verify the current ODOT approaches in inspecting the highway culverts and estimating durability of culvert materials.

6.3.1 Basic Analysis of Data Collected at Concrete Culvert Sites

None of the concrete culverts inspected in the project had any protective coating applied to the concrete surface. No major alignment problems were noticed at any of the concrete culvert sites. Deteriorated concrete headwall existed at many sites where the culvert was at least 35 years old and the soil cover was less than 5 ft (1.52 m). This suggests that the main cause for the severe concrete deterioration might be repeated chloride attacks (from deicing salt applications) and freeze-thaw cycles. The roadway surface had no settlement problems at all the concrete culvert sites. The service life for concrete culvert structures under Ohio roadways may be limited to 70 to 80 years. Table 6.14 summarizes the rating scores each concrete culvert received according to the concrete culvert rating system presented in the ODOT Culvert Management Manual (ODOT, 2003).

Table 6.14: ODOT Rating Scores for Concrete Culverts

Culvert I.D.	PUT-189-10.5	HAN-224-6.84	WAY-103-1.06	LIC-70-13.52	COS-93-11.54	MAD-29-11.37
1. General (Material)	4	7	4	6	4	5
2. Culvert Alignment	7	6	4	6	8	8
3. Culvert Joints	NA	NA	NA	6	NA	NA
4. Top Slab	7	4	7	NA	5	4
5. Abutment Walls	4	NA	4	NA	4	6
6. Headwalls	7	2	6	1	8	10
7. Channel Alignment	8	6	6	6	8	NF
8. Channel Protection	NA	NA	NA	NA	NA	NF
9. Waterway Blockage	8	4	6	8	8	NF
10. Channel Scour	6	9	3	8	NA	NF
11. Pavement	9	8	9	8	7	6
12. Guardrail	NA	8	8	9	8	NA
13. Embankment	7	7	8	7	7	8
● Composite Score*	22	17	19	18	21	23

Table 6.14: ODOT Rating Scores for Concrete Culverts (cont'd)

Culvert I.D.	MAD-142-4.30	FAY-753-2.09	PIK-335-5.18	CLI-28-7.84	BUT-126-2.58	GRE-380-4.97
1. General (Material)	4	3	6	4	4	8
2. Culvert Alignment	9	8	9	6	6	6
3. Culvert Joints	NA	NA	7	NA	NA	5
4. Top Slab	3	2	6	4	6	NA
5. Abutment Walls	4	4	6	3	4	NA
6. Headwalls	2	NA	8	10	7	NA
7. Channel Alignment	NF	7	9	8	7	NA
8. Channel Protection	NF	NA	NA	NA	NA	8
9. Waterway Blockage	NF	8	6	6	7	NA
10. Channel Scour	NF	4	9	8	8	8
11. Pavement	8	8	7	7	8	8
12. Guardrail	NA	8	8	NA	7	8
13. Embankment	4	7	7	8	7	8
● Composite Score*	20	17	34	17	20	19

[Note] * Composite score is obtained by adding the rating scores for:
Items 1, 2, 4, and 5 ---- Cast-in-place concrete box culvert
Items 1 through 3 ---- Jointed circular/elliptic concrete pipe

Table 6.14: ODOT Rating Scores for Concrete Culverts (cont'd)

Culvert I.D.	HIG-124-25.75	HOC-216-1.99	HOC-78-1.05	HOC-216-3.25	HOC-216-3.43	MRG-78-11.34
1. General (Material)	9	8	6	7	7	7
2. Culvert Alignment	8	9	9	9	9	9
3. Culvert Joints	8	NA	NA	NA	NA	NA
4. Top Slab	NA	6	5	7	7	7
5. Abutment Walls	NA	7	6	7	7	7
6. Headwalls	9	10	2	6	2	8
7. Channel Alignment	8	6	6	8	8	7
8. Channel Protection	NA	NA	NA	NA	NA	NA
9. Waterway Blockage	7	4	6	7	4	6
10. Channel Scour	NA	9	6	7	9	6
11. Pavement	8	9	7	8	9	9
12. Guardrail	8	6	NA	NA	NA	NA
13. Embankment	8	7	6	8	8	7
● Composite Score*	25	30	26	30	30	30

Table 6.14: ODOT Rating Scores for Concrete Culverts (cont'd)

Culvert I.D.	MRG-78-24.97	VIN-56-6.85	MEG-338-16.42	ATH-278-0.25	MRG-60-19.95	CUY-480-0.75	CUY-422-15.2
1. General (Material)	4	6	2	9	7	5	8
2. Culvert Alignment	9	9	5	6	9	8	7
3. Culvert Joints	NA	NA	NA	8	NA	7	6
4. Top Slab	4	6	2	NA	7	NA	NA
5. Abutment Walls	5	7	2	NA	7	NA	NA
6. Headwalls	1	3	8	9	2	7	8
7. Channel Alignment	7	7	8	8	6	8	8
8. Channel Protection	NA	NA	NA	NA	NA	8	NA
9. Waterway Blockage	5	4	9	6	8	8	6
10. Channel Scour	4	8	3	9	8	9	9
11. Pavement	9	9	7	9	5	9	9
12. Guardrail	NA	NA	NA	NA	8	NA	NA
13. Embankment	4	4	4	6	4	7	8
● Composite Score*	22	28	11	23	30	20	21

[Note] * Composite score is obtained by adding the rating scores for:
Items 1, 2, 4, and 5 ---- Cast-in-place concrete box culvert
Items 1 through 3 ---- Jointed circular/elliptic concrete pipe

At this point, a simple analysis may be attempted to detect any meaningful trends existing among the data presented in Table 6.14. Results of a basic statistical analysis performed on the key ODOT rating scores are presented in Table 6.15 for the box and circular pipe (RCP) types. It is interesting to note that the average composite score came out to be identical between the two types, although the minimum of some of the average individual rating scores are somewhat higher for the RCP. Among the scores for the concrete box culverts, the alignment had consistently higher scores. Among the RCP culverts, the score on the joint condition had a tendency to be slightly lower than that on the material condition or structural alignment.

Table 6.15: Basic Statistical Summary of Data Presented in Table 6.14

(a) ODOT Scores on Concrete Culverts

Score Category	Cast-In-Place Concrete Box				RCP			
	Min.	Ave.	Max.	Std. Dev.	Min.	Ave.	Max.	Std. Dev.
1. General (Material)	2	5.2	9	1.7	5	7.3	9	1.5
2. Culvert Alignment	4	7.7	9	1.6	6	7.1	9	1.1
3. Culvert Joints	NA	NA	NA	NA	5	6.7	8	1.0
4. Top Slab	2	5.2	7	1.7	NA	NA	NA	NA
5. Abutment Walls	2	5.2	7	1.6	NA	NA	NA	NA
● Composite Score	11	22.9	30	5.6	18	22.9	34	5.1

(b) ODOT Scores Related to Concrete Culvert Performance

Score Category	All Concrete Culverts			
	Min.	Ave.	Max.	Std. Dev.
6. Headwalls	1	5.9	10	3.1
10. Channel Scour	3	7.1	9	2.0
11. Pavement	5	8.0	9	1.1
13. Embankment	4	6.6	8	1.4

Figure 6.24 plots the correlation between the general material rating and culvert age for the concrete culverts. Although the overall trend makes sense, the data points are highly scattered. This may indicate that the age is not the single most influential factor on deterioration of material in concrete culvert structures. A more sophisticated multi-variable statistical analysis is required to identify contributions of several factors on the concrete culvert material rating.

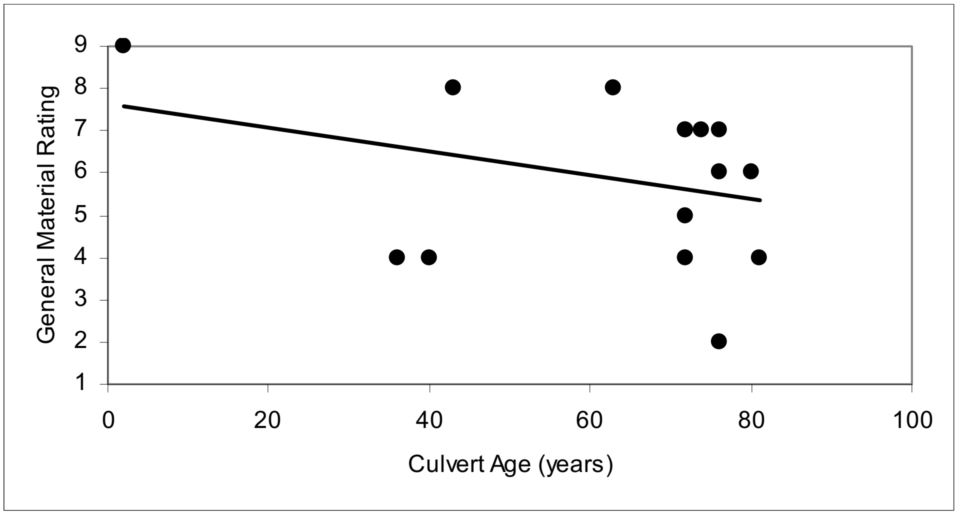


Figure 6.24: Material Rating Vs. Age Plot for Concrete Culverts

Figure 6.25 plots the correlation between the general headwall rating and culvert age for the concrete culverts. Again, the overall trend makes sense. But, the data points are highly scattered. This may indicate that the age is not the single most influential factor on the rate of concrete headwall deteriorations at concrete culvert sites.

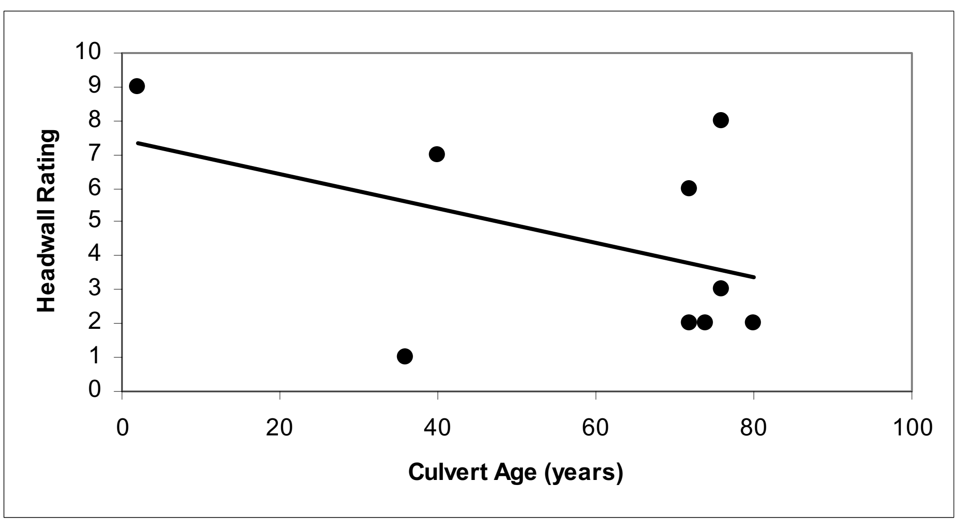


Figure 6.25: Headwall Rating Vs. Age Plot for Concrete Culverts

Table 6.16 summarizes the rating scores each concrete culvert received according to the ORITE concrete culvert rating systems, presented briefly in Chapter 5 and attached in Appendix B.

Table 6.16: ORITE Rating Scores for Concrete Culverts

Culvert I.D.		PUT-189-10.5	HAN-224-6.84	WYA-103-1.06	LIC-70-13.52	COS-93-11.54	MAD-29-11.37
1. Concrete Surface	Top	8	8	8	6	5	6
	Sides	5 (min.)	6 (min.)	2 (min.)	6	4 (min.)	6
	Bottom	NA	NA	NA	6	NA	6
2. Joints	Top	NA	8	NA	7	NA	NA
	Sides	NA	6 (min.)	NA	7	NA	NA
	Bottom	NA	NA	NA	7	NA	NA
3. Invert Paving		NA	NA	NA	8	NA	NA
4. Footings		4	NA	4	NA	NA	NA
5. Inlet End		7	5	3	7	8	3
6. Outlet End		7	5	3	7	8	2
7. Slope & Settlement		8	6	5	6	8	8
8. Horizontal Alignment		7	6	8	7	8	8
9. Roadway Surface		9	8	9	8	7	6
10. Guardrail		NA	8	8	8	8	NA
11. Embankment	Upstream	7	7	8	9	8	8
	Downstream	7	7	8	7	7	8
12. Headwall @ Inlet	Cracking	7	1	5	1	8	7
	Deterioration	7	1	5	1	8	2
	Movement	8	5	7	5	8	8
13. Headwall @ Outlet	Cracking	7	1	6	1	8	6
	Deterioration	7	1	6	1	7	2
	Movement	8	7	8	1	8	8
14. Channel	Alignment	8	6	6	7	8	NA
	Scour	6	9	8	7	NA	NA
	Obstruction	9	4	6	6	8	NA
	Protection	NA	NA	NA	NA	NA	NA
15. Sediment Inside Culvert		8	6	NA	6	6	NA
● Composite Score*		34	28	21	40	36	27

[Note] * The composite score is obtained by adding the rating scores for:
Items 1 (min.), 5, 6, 7, and 8 ---- Cast-in-place concrete box culverts
Items 1 (min.),2 (min.), 5, 6, 7, and 8 ---- RCP and other jointed concrete culverts

Table 6.16: ORITE Rating Scores for Concrete Culverts (cont'd)

Culvert I.D.		MAD-142-4.30	FAY-753-2.09	PIK-335-5.18	CLI-28-7.84	BUT-126-2.58	GRE-380-4.97
1. Concrete Surface	Top	9	2 (min.)	6	4	6	8
	Sides	5 (min.)	4	6	1 (min.)	4 (min.)	8
	Bottom	9	6	NA	NA	NA	8
2. Joints	Top	NA	NA	7	NA	NA	6
	Sides	NA	NA	7	NA	NA	6
	Bottom	NA	NA	NA	NA	NA	6
3. Invert Paving		NA	NA	NA	NA	NA	NA
4. Footings		8	NA	NA	NA	NA	NA
5. Inlet End		5	3	7	8	5	8
6. Outlet End		5	1	7	8	7	8
7. Slope & Settlement		8	8	9	8	5	6
8. Horizontal Alignment		8	8	8	8	7	8
9. Roadway Surface		8	8	7	7	8	8
10. Guardrail		NA	8	8	NA	7	NA
11.Embankment	Upstream	6	5	7	8	8	8
	Downstream	4	7	7	8	6	8
12. Headwall @ Inlet	Cracking	2	NA	8	8	6	NA
	Deterioration	2	NA	7	8	5	NA
	Movement	8	NA	8	8	7	NA
13. Headwall @ Outlet	Cracking	2	NA	8	8	7	NA
	Deterioration	2	NA	7	8	7	NA
	Movement	8	NA	8	8	8	NA
14. Channel	Alignment	8	5	9	8	7	8
	Scour	8	4	9	8	8	8
	Obstruction	8	8	5	6	7	8
	Protection	NA	NA	NA	NA	NA	NA
15. Sediment Inside Culvert		NA	8	NA	NA	NA	8
● Composite Score*		31	22	44	33	28	44

[Note] * The composite score is obtained by adding the rating scores for:
Items 1 (min.), 5, 6, 7, and 8 ---- Cast-in-place concrete box culverts
Items 1 (min.),2 (min.), 5, 6, 7, and 8 ---- RCP and other jointed concrete culverts

Table 6.16: ORITE Rating Scores for Concrete Culverts (cont'd)

Culvert I.D.		HIG-124-25.75	HOC-216-1.99	HOC-78-1.05	HOC-216-3.25	HOC-216-3.43	MRG-78-11.34
1. Concrete Surface	Top	8	7 (min.)	5	7	7	7
	Sides	8	8	5	5 (min.)	NA	7
	Bottom	NA	8	5	NA	NA	5 (min.)
2. Joints	Top	8	NA	NA	NA	NA	NA
	Sides	8	NA	NA	NA	NA	NA
	Bottom	NA	NA	NA	NA	NA	NA
3. Invert Paving		NA	NA	NA	NA	NA	NA
4. Footings		NA	NA	NA	NA	NA	NA
5. Inlet End		8	4	2	7	8	7
6. Outlet End		7	5	2	7	2	7
7. Slope & Settlement		9	9	9	8	8	9
8. Horizontal Alignment		9	8	8	8	8	8
9. Roadway Surface		8	9	6	8	8	9
10. Guardrail		8	9	NA	NA	NA	NA
11. Embankment	Upstream	8	7	7	8	8	6
	Downstream	8	8	7	8	8	6
12. Headwall @ Inlet	Cracking	8	8	1	7	NA	8
	Deterioration	8	8	1	7	NA	7
	Movement	8	8	6	7	NA	8
13. Headwall @ Outlet	Cracking	8	8	3	7	NA	7
	Deterioration	8	8	2	5	NA	7
	Movement	8	8	8	8	NA	8
14. Channel	Alignment	8	7	6	8	8	6
	Scour	9	8	7	7	7	7
	Obstruction	7	5	7	6	3	4
	Protection	NA	NA	NA	9	9	9
15. Sediment Inside Culvert		5	2	4	6	3	5
● Composite Score*		49	33	26	35	33	36

[Note] * The composite score is obtained by adding the rating scores for:
Items 1 (min.), 5, 6, 7, and 8 ---- Cast-in-place concrete box culverts
Items 1 (min.),2 (min.), 5, 6, 7, and 8 ---- RCP and other jointed concrete culverts

Table 6.16: ORITE Rating Scores for Concrete Culverts (cont'd)

Culvert I.D.		MRG-78-24.97	VIN-56-6.85	MEG-338-16.42	ATH-278-0.25	MRG-60-19.95	CUY-480-0.75	CUY-422-15.2
1. Concrete Surface	Top	4 (min.)	7	2 (min.)	9	7	6 (min.)	8
	Sides	4 (min.)	6 (min.)	2 (min.)	9	7	6 (min.)	8
	Bottom	5	6 (min.)	NA	NA	7	7	8
2. Joints	Top	NA	NA	NA	7	NA	7	8
	Sides	NA	NA	NA	7	NA	7	6 (min.)
	Bottom	NA	NA	NA	NA	NA	7	8
3. Invert Paving		NA	NA	NA	NA	NA	NA	NA
4. Footings		NA	NA	NA	NA	NA	NA	NA
5. Inlet End		7	3	8	9	4	7	8
6. Outlet End		2	3	8	9	7	4	8
7. Slope & Settlement		7	9	4	7	9	8	7
8. Horizontal Alignment		8	8	8	8	9	8	8
9. Roadway Surface		8	9	7	9	5	UC	9
10. Guardrail		NA	NA	NA	NA	8	NA	NA
11. Embankment	Upstream	5	4	4	6	3	8	8
	Downstream	4	9	3	6	5	8	8
12. Headwall @ Inlet	Cracking	7	2	8	9	1	7	8
	Deterioration	6	4	8	9	1	7	8
	Movement	7	6	8	9	8	8	8
13. Headwall @ Outlet	Cracking	1	2	8	9	7	8	8
	Deterioration	1	3	8	9	7	8	8
	Movement	6	6	8	9	8	8	8
14. Channel	Alignment	6	6	4	7	6	8	8
	Scour	4	8	6	9	8	9	9
	Obstruction	4	4	8	6	8	8	6
	Protection	NA	NA	NA	NA	NA	8	NA
15. Sediment Inside Culvert		3	6	NA	6	9	6	4
● Composite Score*		28	29	30	49	36	40	45

[Note] * The composite score is obtained by adding the rating scores for:
Items 1 (min.), 5, 6, 7, and 8 ---- Cast-in-place concrete box culverts
Items 1 (min.),2 (min.), 5, 6, 7, and 8 ---- RCP and other jointed concrete culverts

Results of a basic statistical analysis performed on the key ORITE rating scores are presented in Table 6.17 for the box and circular pipe (RCP) types. The average concrete surface rating scores established for three different regions (top, sides, invert), show that concrete material deteriorations are a more concern for the sides and invert than for the top/crown. Statistical results are very similar between the inlet and outlet ends. Statistical results are also similar between the inlet headwall and outlet headwall.

The headwall movement is not a concern at the concrete culvert sites. Table 6.17 confirms that horizontal and vertical alignment problems are generally rare for concrete culvert structures. Finally, the rating scores are very similar for common items between Tables 6.15 and 6.17. This provides validity to the ODOT culvert rating systems, which have lower-resolution than the ORITE rating systems.

Table 6.17: Basic Statistical Summary of Data Presented in Table 6.16

(a) ORITE Scores Related to Concrete Culvert

Score Category		Cast-In-Place Concrete Box				RCP			
		Min.	Ave.	Max.	Std. Dev.	Min.	Ave.	Max.	Std. Dev.
1. Concrete Surface	Top	2	5.7	9	2.0	6	7.6	9	1.0
	Sides	1	4.8	8	1.8	6	7.3	9	1.2
	Invert	5	6.3*	9	1.3	7	7.3	8	0.8
2. Culvert Joints	Top	NA	NA	NA	NA	6	7.3	8	0.8
	Sides	NA	NA	NA	NA	6	6.7	8	0.7
	Invert	NA	NA	NA	NA	6	7.0	8	0.7
5. Inlet End		2	5.5	8	2.1	7	7.4	9	1.2
6. Outlet End		1	5.1	8	2.5	4	6.9	9	1.6
7. Slope & Settlement		4	7.7	9	1.5	6	7.0	9	1.1
8. Horiz. Alignment		6	7.9	9	0.4	7	7.7	9	0.9
● Composite Score		21	31.2	36	5.4	40	42.1	49	6.7

* [Note] The average score is skewed due to a lack of data points.

(b) ORITE Scores Related to Concrete Culvert Performance

Score Category		All Concrete Culverts			
		Min.	Ave.	Max.	Std. Dev.
9. Roadway Surface		5	7.8	9	1.1
11. Embankment	Upstream	3	6.8	9	1.6
	Downstream	3	6.9	9	1.5
12. Headwall @ Inlet	Cracking	1	5.8	9	2.8
	Deterioration	1	5.5	9	2.8
	Movement	5	7.4	9	1.1
13. Headwall @ Outlet	Cracking	1	5.9	9	2.7
	Deterioration	1	5.5	9	2.8
	Movement	1	7.5	9	1.6
14. Channel	Alignment	4	7.0	8	1.2
	Scour	4	7.5	9	1.4
	Obstruction	3	6.3	9	1.6
15. Sediment Inside Culvert		2	5.6	9	1.9

6.3.2 Basic Analysis of Data Collected at Metal Culvert Sites

No stress cracks were found at the bolt lines inside any of the metal culverts. Table 6.18 summarizes the rating scores each metal culvert received according to the metal culvert rating system presented in the ODOT Culvert Management Manual (ODOT, 2003).

Table 6.18: ODOT Rating Scores for Metal Culverts

Culvert I.D.	PAU-66-2.44	DEF-18-20.60	PUT-15-14.78	LIC-16-13.66	GUE-70-8.94	MUS-93-1.76
1. General (Material)	6	7	6	5	5	5
2. Culvert Alignment	8	7	6	6	9	6
3. Culvert Shape	5	4	6	7	3	4
4. Seams/Joints	7	8	8	7	8	6
5. Headwalls	NA	NA	4	4	9	2
6. Channel Alignment	7	8	8	4	8	5
7. Channel Protection	NA	NA	NA	NA	NA	6
8. Waterway Blockage	7	6	5	7	7	5
9. Channel Scour	8	8	3	4	8	5
10. Pavement	8	8	8	9	8	8
11. Guardrail	NA	NA	8	8	8	8
12. Embankment	8	7	8	5	7	7
● Composite Score*	26	26	26	25	25	21

Culvert I.D.	GUE-77-7.85R	KNO-95-0.08	MAD-29-8.80	CLI-124-0.03	HIG-50-19.82	JAC-124-17.12
1. General (Material)	5	4	4	4	6	7
2. Culvert Alignment	8	6	6	7	8	7
3. Culvert Shape	6	3	6	7	7	5
4. Seams/Joints	7	4	7	6	7	7
5. Headwalls	7	NA	3	8	NA	0
6. Channel Alignment	7	NF	8	8	8	6
7. Channel Protection	5	NA	NA	8	8	NA
8. Waterway Blockage	7	NA	8	8	7	5
9. Channel Scour	8	NA	4	6	8	5
10. Pavement	7	8	5	8	6	5
11. Guardrail	8	NA	5	9	7	8
12. Embankment	8	7	4	7	8	8
● Composite Score*	26	17	23	24	28	26

Table 6.18: ODOT Rating Scores for Metal Culverts (cont'd)

Culvert I.D.	PIK-32-15.96	ADA-247-11.87	HOC-595-2.85	HOC-664-17.16	HOC-664-22.40	GAL-7-21.30
1. General (Material)	9	6	4	6	4	2
2. Culvert Alignment	8	6	8	8	3	3
3. Culvert Shape	6	6	7	8	3	7
4. Seams/Joints	7	7	7	8	2	2
5. Headwalls	8	NA	1	3	0	6
6. Channel Alignment	7	6	3	8	8	2
7. Channel Protection	8	NA	NA	NA	NA	6
8. Waterway Blockage	9	6	8	7	6	8
9. Channel Scour	3	NA	0	6	4	6
10. Pavement	8	7	7	3	6	3
11. Guardrail	8	8	NA	NA	8	7
12. Embankment	6	8	4	6	6	3
● Composite Score*	30	25	26	30	12	14

Culvert I.D.	MEG-681-7.94	MEG-681-13.96	HOC-595-4.57	WAS-339-15.25	WAS-60-4.84	LAK-90-14.00	LAK-90-4.20
1. General (Material)	6	5	2	4	5	8	7
2. Culvert Alignment	8	8	7	6	8	9	6
3. Culvert Shape	5	8	6	8	5	8	8
4. Seams/Joints	7	7	8	8	5	8	8
5. Headwalls	2	8	4	6	4	4	6
6. Channel Alignment	5	6	4	8	8	9	6
7. Channel Protection	NA	NA	NA	NA	8	NA	NA
8. Waterway Blockage	4	5	7	8	8	8	7
9. Channel Scour	5	6	5	6	9	4	4
10. Pavement	8	8	6	7	8	9	8
11. Guardrail	8	8	NA	6	8	9	8
12. Embankment	7	7	6	7	5	6	7
● Composite Score*	26	28	23	26	23	33	29

[Note] * Composite Score is obtained by adding the rating scores for Items 1 through 4.

Results of a basic statistical analysis performed on the key ODOT rating scores are presented in Table 6.19 for the metal culverts. The average rating score was the lowest on the general material conditions. The second lowest average rating score was related to the shape. The highest average rating score was associated with the culvert alignment. The standard deviation of the rating scores was very similar among the four key performance categories. The average composite score among the metal culverts came out to be slightly better than the average composite score among the concrete culverts (refer to Table 6.17).

Table 6.19: Basic Statistical Summary of Data Presented in Table 6.18

(a) ODOT Scores on Metal Culverts

Score Category	Metal Culverts:			
	Min.	Ave.	Max.	Std. Dev.
1. General (Material)	2	5.3	9	1.6
2. Culvert Alignment	3	6.9	9	1.5
3. Culvert Shape	3	5.9	8	1.6
4. Seams/Joints	2	6.6	8	1.7
● Composite Score	12	24.7	33	4.6

(b) ODOT Scores Related to Metal Culvert Performance

Score Category	Metal Culverts:			
	Min.	Ave.	Max.	Std. Dev.
5. Headwalls	0	4.5	9	2.7
9. Channel Scour	0	5.4	9	2.1
10. Pavement	3	7.0	9	1.6
12. Embankment	3	6.5	8	1.4

Figure 6.26 plots the correlation between the general material rating and culvert age for the metal culverts. Although the overall trend is as expected, there is a considerable degree of scattering in the data point distribution especially for the age of 40 to 50 years. This may indicate that the age is not the single most influential factor on deterioration of material in metal culvert structures. A more sophisticated multi-variable statistical analysis is required to identify contributions of several factors on the metal culvert material rating. The plot indicates that the service life of metal culverts may be limited to less than 70 years in Ohio.

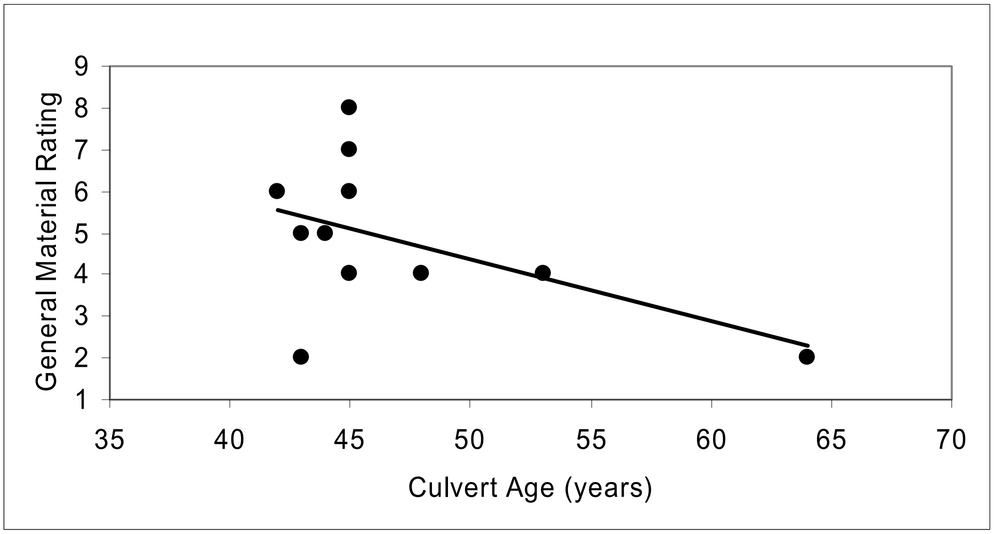


Figure 6.26: General Material Rating vs. Culvert Age Plot for Metal Culverts

Figure 6.27 plots the correlation between the general headwall rating and the culvert age for the metal culverts. The data points are so scattered that it is difficult to discern any clear trends among the data points. This may indicate that the age is not the single most influential factor on the rate of concrete headwall deteriorations at metal culvert sites.

Figure 6.27: Headwall Rating Vs. Age for Metal Culverts

Table 6.20 summarizes the rating scores each metal culvert received according to the ORITE metal culvert rating systems, presented briefly in Chapter 5 and attached in Appendix C.

Table 6.20: ORITE Rating Scores for Metal Culverts

Culvert I.D.		PAU-66-2.44	DEF-18-20.60	PUT-15-14.78	LIC-16-13.66	GUE-70-8.94	MUS-93-1.76
1. Metal Plate	Top	8	8	8	7	8	7
	Sides	7	6 (min.)	8	8	8	7
	Invert	4 (min.)	NA	5 (min.)	3 (min.)	5 (min.)	5 (min.)
2. Joints & Seams	Top	8	6	8	6	8	6 (min.)
	Sides	8	6	8	6	8	8
	Invert	NA	NA	8	5 (min.)	8	7
3. Inlet End		5	7	7	5	8	5
4. Outlet End		5	7	4	5	5	8
5. Shape		7	6	8	7	6	5
6. Deflection		7	6	8	6	4	5
7. Protective Coating		3	NA	NA	NA	NA	NA
8. Invert Paving		NA	2	NA	NA	NA	NA
9. Footing		NA	NA	NA	NA	NA	NA
10. Slope & Settlement		8	6	8	6	6	8
11. Horizontal Alignment		8	8	8	7	8	8
12. Roadway Surface		8	8	8	8	8	8
13. Guardrail		NA	NA	8	8	8	8
14. Embankment	Upstream	8	7	8	4	8	7
	Downstream	8	7	7	7	7	7
15. Headwall @ Inlet	Cracking	NA	NA	4	7	9	NA
	Deterioration	NA	NA	4	2	9	NA
	Movement	NA	NA	8	8	9	NA
16. Headwall @ Outlet	Cracking	NA	NA	2	7	8	NA
	Deterioration	NA	NA	2	5	8	NA
	Movement	NA	NA	2	4	8	NA
17. Channel	Alignment	7	8	8	7	8	7
	Scour	8	8	3	4	7	5
	Obstruction	7	7	5	4	7	6
	Protection	NA	NA	NA	NA	NA	NA
18. Sediment Inside Culvert		6	5	7	4	8	5
● Composite Score *		52	52	56	44	50	50

[Note] * Composite Score is obtained by adding the rating scores of Items 1 (min.), 2 (min.), 3, 4, 5, 6, 10, and 11.

Table 6.20: ORITE Rating Scores for Metal Culverts (cont'd)

Culvert I.D.		GUE-77-7.85R	KNO-95-0.08	MAD-29-8.80	CLI-124-0.03	HIG-50-19.82	JAC-124-17.12
1. Metal Plate	Top	7	8	6	6	8	8
	Sides	5 (min.)	8	6	4	8	8
	Invert	6	3 (min.)	2 (min.)	3 (min.)	6 (min.)	NA
2. Joints & Seams	Top	8	4	7	5	8	8
	Sides	6 (min.)	4	7	5	8	8
	Invert	8	4	7	5	7 (min.)	8
3. Inlet End		4	5	4	7	7	5
4. Outlet End		6	5	5	7	7	5
5. Shape		7	5	7	7	7	5
6. Deflection		7	5	7	7	7	5
7. Protective Coating		NA	NA	NA	NA	NA	NA
8. Invert Paving		NA	NA	NA	NA	NA	3
9. Footing		NA	NA	NA	NA	NA	NA
10. Slope & Settlement		7	8	8	6	7	7
11. Horizontal Alignment		8	6	8	8	8	8
12. Roadway Surface		7	8	6	8	6	5
13. Guardrail		8	NA	5	9	8	8
14.Embank-ment	Upstream	8	7	4	7	8	8
	Downstream	8	7	4	7	8	8
15. Headwall @ Inlet	Cracking	7	NA	2	8	NA	0
	Deterioration	6	NA	1	8	NA	0
	Movement	8	NA	8	8	NA	0
16. Headwall @ Outlet	Cracking	7	NA	2	7	NA	NA
	Deterioration	7	NA	1	7	NA	NA
	Movement	8	NA	7	8	NA	NA
17. Channel	Alignment	7	NF	8	8	8	6
	Scour	8	NF	7	7	8	7
	Obstruction	5	NF	7	8	8	6
	Protection	NA	NF	NA	8	8	NA
18. Sediment Inside Culvert		5	5	6	7	8	4
● Composite Score *		50	41	48	50	56	51

[Note] * Composite Score is obtained by adding the rating scores of Items 1 (min.), 2 (min.), 3, 4, 5, 6, 10, and 11.

Table 6.20: ORITE Rating Scores for Metal Culverts (cont'd)

Culvert I.D.		PIK-32-15.96	ADA-247-11.87	HOC-595-2.85	HOC-664-17.16	HOC-664-22.40	GAL-7-21.30
1. Metal Plate	Top	9	6	7	8	7	7
	Sides	9	7	7	6 (min.)	7	7
	Invert	9	6	2 (min.)	NA	3 (min.)	1 (min.)
2. Joints & Seams	Top	7	7	8	8	8	1
	Sides	7	5 (min.)	8	8	8	1
	Invert	7	NA	7 (min.)	NA	1 (min.)	1
3. Inlet End		9	8	3	4	1	3
4. Outlet End		3	8	2	5	3	2
5. Shape		8	7	7	7	2	NA
6. Deflection		8	7	7	7	5	NA
7. Protective Coating		NA	NA	NA	NA	7	2
8. Invert Paving		8	NA	NA	NA	NA	NA
9. Footing		NA	NA	NA	NA	NA	NA
10. Slope & Settlement		8	8	7	7	3	2
11. Horizontal Alignment		7	8	8	8	3	2
12. Roadway Surface		8	7	6	4	5	1
13. Guardrail		8	8	NA	NA	8	7
14.Embank-ment	Upstream	9	8	4	6	7	8
	Downstream	6	8	4	8	7	2
15. Headwall @ Inlet	Cracking	9	NA	2	3	0	7
	Deterioration	9	NA	2	3	0	7
	Movement	9	NA	2	3	0	7
16. Headwall @ Outlet	Cracking	9	NA	1	2	3	NA
	Deterioration	9	NA	1	2	3	NA
	Movement	9	NA	1	2	3	NA
17. Channel	Alignment	7	6	NA	8	8	8
	Scour	3	8	NA	7	6	5
	Obstruction	9	6	NA	7	6	6
	Protection	8	NA	NA	NA	NA	NA
18. Sediment Inside Culvert		9	8	7	4	4	8
● Composite Score *		59	57	43	52	21	11

[Note] * Composite Score is obtained by adding the rating scores of Items 1 (min.), 2 (min.), 3, 4, 5, 6, 10, and 11.

Table 6.20: ORITE Rating Scores for Metal Culverts (cont'd)

Culvert I.D.		MEG-681-7.94	MEG-681-13.96	HOC-595-4.57	WAS-339-15.25	WAS-60-4.84	LAK-90-14.00	LAK-90-4.20
1. Metal Plate	Top	7	8	8	8	8	8	7
	Sides	8	8	8	8	8	8	7
	Invert	6 (min.)	5 (min.)	3 (min.)	3 (min.)	4 (min.)	NA	NA
2. Joints & Seams	Top	6	7	8	8	6 (min.)	8	7
	Sides	6	8	8	8	8	8	7
	Invert	6	NA	5 (min.)	7 (min.)	7	NA	NA
3. Inlet End		3	2	2	4	4	8	8
4. Outlet End		4	5	3	3	3	8	6
5. Shape		5	7	8	8	5	8	8
6. Deflection		5	7	8	8	5	8	8
7. Protective Coating		3	NA	NA	2	NA	NA	NA
8. Invert Paving		2	NA	2	NA	NA	9	8
9. Footing		NA	NA	NA	NA	NA	NA	NA
10. Slope & Settlement		7	8	6	8	8	9	8
11. Horizontal Alignment		8	8	8	8	8	8	8
12. Roadway Surface		8	8	5	7	8	9	8
13. Guardrail		8	8	NA	6	8	9	8
14.Embank-ment	Upstream	7	7	3	7	3	6	7
	Downstream	8	8	7	7	8	7	8
15. Headwall @ Inlet	Cracking	7	8	2	8	8	8	8
	Deterioration	7	8	7	6	8	7	6
	Movement	8	8	7	8	5	6	6
16. Headwall @ Outlet	Cracking	NA	7	3	8	8	5	7
	Deterioration	NA	8	7	6	7	7	7
	Movement	NA	8	5	8	8	4	6
17. Channel	Alignment	5	6	6	7	8	9	5
	Scour	4	6	3	7	8	6	4
	Obstruction	5	5	5	6	8	8	7
	Protection	NA	NA	NA	NA	8	NA	NA
18. Sediment Inside Culvert		8	8	8	7	7	8	8
● Composite Score *		44	49	43	49	43	65	60

[Note] * Composite Score is obtained by adding the rating scores of Items 1 (min.), 2 (min.), 3, 4, 5, 6, 10, and 11.

Results of a basic statistical analysis performed on the key ORITE rating scores are presented in Table 6.21 for all the metal culverts inspected. The average metal surface rating scores established for three different regions (top, sides, invert), show that metal deteriorations are a more concern for the invert region than for the crown or side region. In the table, the lowest average rating score belongs to the condition of invert metal plate. Statistical results are very similar between the inlet and outlet ends.

Statistical results are also similar between the inlet headwall and outlet headwall. The headwall movement is not a concern at the metal culvert sites. The average scores associated with the horizontal alignment, vertical alignment, and roadway surface are slightly lower among the metal culverts than among the concrete culverts (see Table 6.17). In contrast, the rating scores for the embankment slopes are very similar among the concrete and metal culverts. Finally, the rating scores are very similar for common items between Tables 6.19 and 6.21. This provides validity to the ODOT culvert rating systems, which are lower-resolutioned than the ORITE rating systems.

Table 6.21: Basic Statistical Summary of Data Presented in Table 6.20

(a) ORITE Scores Directly Related to Metal Culverts

Score Category		Metal Culverts:			
		Min.	Ave.	Max.	Std. Dev.
1. Metal Plate	Top	6	7.5	9	0.8
	Sides	4	7.2	9	1.1
	Invert	1	4.2	9	1.9
2. Joints & Seams	Top	1	6.8	8	1.6
	Sides	1	6.9	8	1.7
	Invert	1	6.0	8	2.2
3. Inlet End		3	5.1	9	2.2
4. Outlet End		2	5.0	8	1.8
5. Culvert Shape		2	6.5	8	1.4
6. Deflection		4	6.5	8	1.2
10. Slope & Settlement		2	7.0	8	1.6
11. Horizontal Alignment		2	7.2	8	1.6
● Composite Score		11	47.8	65	11.1

(b) ORITE Scores Related to Metal Culvert Performance

Score Category		Metal Culverts			
		Min.	Ave.	Max.	Std. Dev.
9. Roadway Surface		5	6.9	9	1.8
11. Embankment	Upstream	3	6.6	9	1.7
	Downstream	2	6.9	8	1.5
12. Headwall @ Inlet	Cracking	0	5.6	9	3.0
	Deterioration	0	5.3	9	3.0
	Movement	0	6.2	9	2.8
13. Headwall @ Outlet	Cracking	1	5.4	9	2.6
	Deterioration	1	5.4	9	2.6
	Movement	1	5.7	9	2.6
14. Channel	Alignment	5	7.2	9	1.0
	Scour	3	6.0	8	1.8
	Obstruction	4	6.4	9	1.2
15. Sediment Inside Culvert		4	6.6	9	1.6

6.33 Basic Analysis of Data Collected at Thermoplastic Pipe Culvert Sites

It is well known that the buried thermoplastic pipes derive their load carrying capacity and stability through interactions with backfill soil envelope. So, it is important to have data (type, moisture content, degree of compaction) on the backfill soil for any installed thermoplastic pipe culvert. However, no detailed backfill soil data were available for the thermoplastic pipes. The case of NOB-145-3.59 proved that thermoplastic pipe can perform for many years in severe environmental conditions that may be very detrimental to other culvert types.

Table 6.22 summarizes the rating scores each plastic culvert received according to the thermoplastic pipe culvert rating system presented in the ODOT Culvert Management Manual (ODOT, 2003).

Table 6.22: ODOT Rating Scores for Thermoplastic Pipe Culverts

Culvert I.D.	FAI-33b-Sta. 446+92	PER-13-11.14	FAI-33b-Sta. 587+96	FAI-22-Sta. 17+20	FAI-33b-SR18-Sta. 86+00
1. General (Material)	9	9	9	9	9
2. Culvert Alignment	6	7	9	6	7
3. Culvert Shape	6	6	8	9	6
4. Culvert Joints	7	7	9	8	8
5. Headwalls	9	NA	9	9	9
6. Channel Alignment	UC	9	UC	UC	UC
7. Channel Protection	UC	NA	UC	UC	UC
8. Waterway Blockage	UC	9	UC	UC	UC
9. Channel Scour	UC	3	UC	UC	UC
10. Pavement	UC	6	UC	UC	UC
11. Guardrail	UC	9	UC	UC	UC
12. Embankment	UC	7	UC	UC	UC
• Composite Score*	28	29	35	32	30

[Note] * Composite Score is obtained by adding the rating scores for Items 1 through 4.

Table 6.22: ODOT Rating Scores for Thermoplastic Pipe Culverts (cont'd)

Culvert I.D.	FAI-33b-SR18-Sta. 96+00	FAI-33b-Ramp J (Sta. 488+07)	MEG-124-30.17	HOC-327-2.70	NOB-145-3.59
1. General (Material)	9	9	8	9	8
2. Culvert Alignment	9	9	7	6	7
3. Culvert Shape	9	9	6	5	6
4. Culvert Joints	9	9	8	8	8
5. Headwalls	10	9	4	NA	NA
6. Channel Alignment	UC	7	8	7	8
7. Channel Protection	UC	NA	NA	NA	6
8. Waterway Blockage	UC	8	8	5	8
9. Channel Scour	UC	9	6	8	9
10. Pavement	UC	NA	8	4	8
11. Guardrail	UC	NA	NA	NA	NA
12. Embankment	UC	UC	5	6	8
● Composite Score*	36	36	29	28	29

[Note] * Composite Score is obtained by adding the rating scores for Items 1 through 4.

Results of a basic statistical analysis performed on the key ODOT rating scores are presented in Table 6.23 for thermoplastic pipe culverts. The culvert shape received the lowest average rating score, followed by the culvert alignment.

Table 6.23: Basic Statistical Summary of Data Presented in Table 6.22

(a) ODOT Scores on Thermoplastic Pipe Culverts

Score Category	Thermoplastic Pipe Culverts			
	Min.	Ave.	Max.	Std. Dev.
1. General (Material)	8	8.8	9	0.4
2. Culvert Alignment	6	7.3	9	1.2
3. Culvert Shape	5	7.0	9	1.5
4. Culvert Joints	7	8.1	9	0.7
● Composite Score	28	31.2	36	3.1

(b) ODOT Scores Related to Thermoplastic Pipe Culvert Performance

Score Category	Thermoplastic Pipe Culverts			
	Min.	Ave.	Max.	Std. Dev.
5. Headwalls	4	8.4	10	1.8
9. Channel Scour	3	7.0	9	2.5
10. Pavement	4	6.5	8	1.7
12. Embankment	5	6.5	8	1.3

Table 6.24 summarizes the rating scores each thermoplastic pipe culvert received according to the ORITE thermoplastic pipe culvert rating system, presented briefly in Chapter 5 and attached in Appendix D.

Table 6.24: ORITE Rating Scores for Thermoplastic Pipe Culverts

Culvert I.D.		FAI-33b-Sta. 446+92	PER-13-11.14	FAI-33b-Sta. 587+96	FAI-22-Sta. 17+20	FAI-33b-SR18-Sta. 86+00
1. Deflection		4	6	9	9	9
2. Distortion		5	6	8	9	9
3. Wall @ Crown	Cracking	9	8	9	9	9
	Buckling	9	9	NA	9	7
4. Wall @ Shoulder	Cracking	9	8	9	9	9
	Buckling	9	9	NA	NA	7
5. Wall @ Springline	Cracking	9	8	9	9	9
	Buckling	4	5	NA	NA	7
6. Wall @ Haunch	Cracking	9	8	9	9	9
	Buckling	9	9	NA	NA	7
7. Wall @ Invert	Cracking	9	8	9	9	NA
	Buckling	9	9	NA	NA	NA
8. Joints		8	8	9	9	8
9. Inlet End		9	8	9	9	NA
10. Outlet End		9	8	9	9	9
11. Slope & Settlement		7	6	9	7	9
12. Horizontal Alignment		9	8	9	9	NA
13. Roadway Surface		UC	5	UC	UC	UC
14. Guardrail		NA	8	UC	UC	UC
15.Embank-ment	Upstream	UC	7	UC	9	UC
	Downstream	UC	6	UC	9	UC
16.Headwall @ Inlet	Cracking	9	NA	NA	9	NA
	Deterioration	9	NA	NA	9	NA
	Movement	9	NA	NA	9	NA
17.Headwall @ Outlet	Cracking	9	NA	NA	9	9
	Deterioration	9	NA	NA	9	9
	Movement	9	NA	NA	9	9
18.Channel	Alignment	UC	3	UC	UC	UC
	Scour	UC	3	UC	UC	UC
	Obstruction	UC	8	UC	UC	UC
	Protection	UC	NA	UC	UC	UC
19. Sediment Inside Culvert		8	8	5	8	4
● Composite Score*		55	55	71	70	NA

[Note] * Composite Score is obtained by adding the rating scores of Item 1, Item 2, minimum of 3 through 7, and Items 8 through 12.

Table 6.24: ORITE Rating Scores for Thermoplastic Pipe Culverts (cont'd)

Culvert I.D.		FAI-33b-SR18-Sta. 96+00	FAI-33b-Ramp J Sta. 488+07	MEG-124-30.17	HOC-327-2.70	NOB-145-3.59
1. Deflection		9	9	5	3	5
2. Distortion		9	9	6	6	6
3. Wall @ Crown	Cracking	9	9	9	9	8
	Buckling	NA	NA	9	9	9
4. Wall @ Shoulder	Cracking	9	9	9	9	8
	Buckling	NA	NA	9	9	9
5. Wall @ Springline	Cracking	9	9	9	9	8
	Buckling	NA	NA	6	9	9
6. Wall @ Haunch	Cracking	9	9	9	NA	8
	Buckling	NA	NA	9	NA	9
7. Wall @ Invert	Cracking	9	9	9	NA	8
	Buckling	NA	NA	9	NA	9
8. Joints		9	9	8	8	9
9. Inlet End		9	9	8	9	7
10. Outlet End		9	9	8	9	7
11. Slope & Settlement		9	7	2	6	5
12. Horizontal Alignment		9	9	6	7	7
13. Roadway Surface		UC	UC	8	4	8
14. Guardrails		UC	UC	NA	NA	NA
15.Embank-ment	Upstream	UC	UC	8	5	8
	Downstream	UC	UC	8	6	8
16.Headwall @ Inlet	Cracking	9	9	NA	NA	NA
	Deterioration	9	9	NA	NA	NA
	Movement	9	7	NA	NA	NA
17.Headwall @ Outlet	Cracking	9	9	NA	NA	NA
	Deterioration	9	8	NA	NA	NA
	Movement	9	NA	NA	NA	NA
18.Channel	Alignment	UC	7	8	7	7
	Scour	UC	9	8	9	9
	Obstruction	UC	8	7	5	8
	Protection	UC	NA	NA	NA	6
19. Sediment Inside Culvert		NA	6	8	4	8
● Composite Score*		72	70	49	57	54

[Note] * Composite Score is obtained by adding the rating scores of Item 1, Item 2, minimum of 3 through 7, and Items 8 through 12.

Results of a basic statistical analysis performed on the key ORITE rating scores are presented in Table 6.25 for thermoplastic pipe culverts. The average wall surface rating scores established for five different regions (crown, shoulder, springline, haunch, and invert), show that the springline is the most common region where signs of structural distress tend to develop first. In the table, the lowest average rating scores occur for the deflection and settlement conditions. Many average scores are high in the table, because the average age among the ten thermoplastic pipe culverts was only about 5 years. Statistical results are very similar between the inlet and outlet ends. Statistical results are also similar between the inlet headwall and outlet headwall. Finally, the rating scores are very similar for common items between Tables 6.23 and 6.25. This provides validity to the ODOT culvert rating systems, which are lower-resolutioned than the ORITE rating systems.

Table 6.25: Basic Statistical Summary of Data Presented in Table 6.24

(a) ORITE Scores on Thermoplastic Pipe Culverts

Score Category	Thermoplastic Pipe Culverts			
	Min.	Ave.	Max.	Std. Dev.
1. Deflection	3	6.8	9	2.3
2. Distortion	6	7.3	9	1.6
3. Wall Surface @ Crown	7	8.6	9	0.7
4. Wall Surface @ Shoulder	7	8.6	9	0.7
5. Wall Surface @ Springline	4	7.5	9	1.8
6. Wall Surface @ Haunch	7	8.6	9	0.7
7. Wall Surface @ Invert	8	8.8	9	0.4
8. Culvert Joints	8	8.5	9	0.5
9. Inlet End	7	8.6	9	0.7
10. Outlet End	7	8.6	9	0.7
11. Slope & Settlement	2	6.7	9	2.1
12. Horizontal Alignment	6	8.1	9	1.2
● Composite Score	49	61.4	72	8.6

(b) ORITE Scores Related to Thermoplastic Pipe Culvert Performance

Score Category		Thermoplastic Pipe Culverts			
		Min.	Ave.	Max.	Std. Dev.
9. Roadway Surface		4	6.3	8	1.8
11. Embankment	Upstream	5	7.4	9	1.4
	Downstream	6	7.4	9	1.2
12. Headwall @ Inlet	Cracking	9	9.0	9	0.0
	Deterioration	9	9.0	9	0.0
	Movement	7	8.5	9	0.9
13. Headwall @ Outlet	Cracking	9	9.0	9	0.0
	Deterioration	8	8.8	9	0.4
	Movement	9	9.0	9	0.0
14. Channel	Alignment	3	6.4	8	1.7
	Scour	3	7.6	9	2.3
	Obstruction	5	7.2	8	1.2
15. Sediment Inside Culvert		4	6.6	8	1.7

CHAPTER 7: STATISTICAL ANALYSIS AND RISK ASSESSMENT

7.1 INTRODUCTION

Now that the culvert inventory and performance data have been presented in the previous chapter for all sixty (60) structures inspected in the field, Objectives 4 (verification of the ODOT's new culvert inspection procedures), 5 (risk assessment of the culverts on the inventory), and 7 (review of ODOT culvert durability assessment procedures) can be addressed effectively with use of statistical analysis.

Objective 4 was achieved by performing a variety of statistical analysis for each major culvert type, using the data collected by the ODOT rating system and the proposed rating system separately. Statistically significant parameters can be compared between the two sets of analysis to determine if the ODOT system has all the important elements in its culvert rating procedure. This strategy is possible since the proposed system has higher resolution in the data. The durability assessment formulas developed by ODOT (1982) can be retested using the data collected in the current study in response to Objective 7. Finally, a comprehensive culvert risk assessment method (objective 5) can be proposed based on the results of the statistical analysis and the basic concepts outlined in NCHRP Report 251 (1982).

7.2 OVERVIEW OF STATISTICAL ANALYSIS

Regression analysis was performed on the data collected for the concrete and metal culverts, using SPSS (Statistical Package for Social Science). Two major analytical procedures were applied to the data:

- Linear regression analysis (forward selection, backward elimination, stepwise iteration, analysis of covariance)
- Nonlinear regression analysis.

Four variations of the linear regression analysis were applied to each set of culvert data. No regression analysis was performed for the thermoplastic pipe culverts, because the sample population size was small (only 10), and most of them had relatively short service lives. For each analytical procedure, a number of tools (null hypothesis testing, t-test, F-test, plots of residuals, and normality assumption check) were utilized to verify the analytical results. The following sections describe each part of the procedures and tools.

7.3 LINEAR REGRESSION ANALYSIS

7.3.1 General

Linear regression analysis may be justified in the current study, since the true correlation between the dependent variable and independent variables is unknown. The range of values is relatively narrow for many of the independent variables. The linear regression model fits the data to the following general equation:

$$Y = a_0 + a_1X_1 + a_2X_2 + \ldots\ldots + a_nX_n \qquad \text{Eq. 7.1}$$

where: Y = dependant variable; $X_1, X_2, \ldots, X_n$ = independent (predictor) variables; and $a_0, a_1, \ldots, a_n$ = parameters with unknown values (note: a_0 = intercept value).

A least square method was used to select the proper values for the parameter a_i's such that the sum of the squares of the difference between actual and predicted values of the dependant variable is minimized for the given values of independent variable. When large numbers of variables exist in the data, the linear regression analysis is performed in a stepwise fashion to find the most optimum linear model.

7.3.2 Stepwise Linear Regression Analysis

Stepwise linear regression analysis performed the linear regression procedure one step at a time. Three types of the stepwise linear regression analysis were attempted (forward selection, backward elimination, and stepwise iteration) to search for the optimum linear model. Forward Selection (FS) begins with no predictor variable in the model. The FS procedure adds first the most significant variable to the model and then the next most significant variable at each succeeding step until a satisfactory fit is achieved or until all predictors have been added. The termination of the forward selection process is decided by t-test and F-test results. Backward Elimination (BE) begins with all the predictor variables in the model. Variables are deleted one at a time until a satisfactory fit is achieved. As for the FS procedure, termination of the elimination process is based on the t-test and F-test outcome. Stepwise Iteration (SI) is similar to the FS procedure. However, at each stage of the procedure the deletion of early selected variables is permitted. It thus combines features of both FS and BE procedures. This improvement over the FS is to ensure the continued effectiveness of variables that have been added into the model at earlier stages.

7.3.3 Analysis of Covariance

Analysis of covariance (ANCOVA) was also employed in the linear regression analysis. An equation relating the dependant variable to chosen independent variables, called covariance, was formed. Then, the mean values of the dependent variable for ranges of remaining independent variables or any combination of ranges were adjusted for effect of the covariates. These adjusted means could then be observed to determine what ranges of the selected independent variables differ in effect on the dependent variable.

7.3.4 Linear Regression Model Verifications

In order to determine the reliability of any of the linear models, t-test and F-test were performed. These tests acted as decision makers in the production of the best possible model. The t-test was performed to test a single correlation coefficient or single parameter, while F-test was performed to examine the adequacy of the model. In cases where the relationship between the dependant variable and an independent is shown to be significant through the t-test, the independent variable is an important predictor of the dependant variable. The null hypothesis was H_o: $a_i = 0$, and was compared with an alternative hypothesis H_a: $a_i \neq 0$. If the variable X_i provides no information for the prediction of Y, the null hypothesis will be accepted. The standard level of significance of 0.05 was chosen for the analysis. With this level of significance, meaning there is at most a 5% chance that the results may be due to random variation in the sample. If the probability, P, is less than 0.05, the null hypothesis will be rejected. The same level will be used for the rejection region of the F test.

Sample multiple coefficient of determination R^2 was calculated. It is a measure of overall prediction. It also indicates how well the model fits the observation data and represents the utility of the entire model. In general, the larger the R^2, the better the model fits the data. The R^2 value is often adjusted to take into account the effect of the number of the observations and the number of predictor variables. The adjustment is made, because R^2 can be arbitrarily close to 1.0 if the number of predictor variables is too close to the number of observations. The adjusted R^2 value is always less than R^2. Equations 7.2 and 7.3 show R^2 and adjusted R^2 calculations.

$$R^2 = 1 - \frac{SSE}{TSS} \qquad \text{Eq.7.2}$$

$$R^2_{adjusted} = 1 - a\frac{SSE}{TSS} \qquad \text{Eq.7.3}$$

where SSE = error sum of square $\sum(y_i - \hat{y_i})^2$; TSS = total sum of square. $\sum(y_i - \bar{y}_i)^2$;

y_i = observed value of y; $\hat{y_i}$ = fitted value of y; $\bar{y}_i$ = mean of the observed y values; a = (n-1)/(n-p-1); n = sample size; and p = number of predictors (independent variables).

A scatter plot for residuals (difference between observed and predicted value) was checked. If the residuals behave randomly, it suggests that the model fits the data well. On the other hand, if non-random structure is evident in the residuals, it is a clear sign that the model fits the data poorly. The Normality assumption was checked. The Regression analysis is based on the assumption that for any configuration of the independent variables the random error is normally distributed with a mean value of zero. In order to determine if the data satisfied this assumption, a relative frequency distribution of the residuals was required and the resulting histogram of the residuals should not be skewed.

7.4 NONLINEAR REGRESSION ANALYSIS

Nonlinear regression aims to describe the relationship between a response variable and one or more explanatory variables in a non-linear fashion. As pointed out in the previous chapter, the conditions of a culvert may not decline at a constant rate over the years of service. The rate of degradation may be very slow during the initial years and may start increasing once a certain minimum age is reached. This suggests a nonlinear relationship between the dependent variable (general material rating) and independent variables. Nonlinear regression analysis was performed for the concrete and metal culvert data by using the following model:

$$Y = a_0 X_1^{a1} X_2^{a2} \ldots X_n^{a_n} \qquad \text{Eq. 7.4}$$

One reason for selecting the above model was that it was used to analyze the data in the ODOT Culvert Durability Study (ODOT 1986). A trial and error procedure was used to find the best fit by using SPSS software. Best fit was chosen with respect to the following:

1- Coefficient of determination R^2
2- Minimum sum of squares of the difference between actual and predicted values

3- Check the 95% confidence interval (C.I) for each coefficient. C.I is an interval computed from the data that has a 95% probability of producing an interval containing the true value of the coefficient.

7.5 COLLECTED DATA

Collected data for each culvert included inventory data and field inspection data (primary and secondary) as shown below:

- Inventory Data

Inventory data for each culvert includes most of the following information:

1- Location (ODOT district, county, route, mile-marker)

2- Culvert shape and material

3- Culvert wall thickness (in inches)

4- Type of protective coating (if any)

5- Culvert age (in years)

6- Original dimensions (rise or diameter in feet, span in feet)

7- Information about invert paving (if any)

8- Height of cover (in feet)

9- Headwall type

10- Average daily traffic (ADT)

11- Any maintenance and past inspection records.

- Field Inspection Data

Includes both Primary and secondary data as shown below:

- **Primary Data**

Primary data varies depending on the type of the culvert.

Steel Culverts

- Rise and span dimensions (to determine the deflection)
- Shape (signs of distortions and flattening)
- Steel plate surface (corrosion, pitting)
- Seams and joints (corrosion, bolt-hole cracks, opening, backfill infiltration)
- Slope and settlement including sagging
- Alignment (related to joint tightness and settlement)
- Coating (condition, bonding to steel)
- Invert paving (condition)
- Inlet and outlet conditions

Concrete Culverts

- Rise and span dimensions (in inches)
- Concrete surface conditions (signs of cracking, spalling, scalling)
- Exposed and corroding steel reinforcement bars
- Joints (opening, backfill infiltration, and cracks)
- Slope and settlement including sagging
- Alignment (related to joint tightness and settlement)
- Coating (condition, bonding to steel)
- Inlet and outlet conditions

Thermoplastic Culverts

- Vertical and horizontal diameters (to determine the deflection)
- Shape (signs of distortions and flattening)
- Wall surface (signs of cracking and buckling)
- Joints (opening, backfill infiltration, and cracks)
- Slope and settlement including sagging
- Alignment (related to joint tightness and settlement)
- Inlet and outlet conditions
- Backfill type and conditions.

- **Secondary Data**

- Headwalls at inlet and outlet
- Channel inlet and outlet
- Roadway surface and guardrail
- Upstream and downstream embankment slopes (general conditions)
- Sediment depth inside the culvert
- Flow velocity
- pH of drainage water

7.6 RESULTS OF LINEAR REGRESSION ANALYSIS

This section presents the results of the linear regression analysis performed for the concrete and metal culvert data. The analysis was made for the data based on the ODOT and proposed rating systems. In each analysis, all four variations (FS, BE, SI, ANCOVA) of the linear regression analysis competed to produce the best outcome.

Results presented here consist of standardized and unstandardized coefficients. The standardized coefficients reflect the importance of each independent variable on the model. They were calculated by transforming the data into the standard scale of *Z*-score. *Z*-score for the observation X can be calculated by subtracting the mean of the data from X and then divide it by the standard deviation of the data. The unstandardized coefficients were calculated based on the data without any transformation.

7.6.1 Linear Regression Analysis of Metal Culvert Data

Table 7.1 presents a list of the independent variables for the metal culverts as well as their units, ranges, and symbols.

7.6.1.1 Linear Regression Analysis of Metal Culvert Data Based on ODOT Rating System

Linear regression analysis was performed by the using general rating as the dependant variable and all the independent variables listed in Table 7.1. The age, rise, and culvert type were significant independent variables to predict the general rating (GR) for the metal culverts based on the ODOT metal culvert rating system.

As shown in Table 7.2, P-values for all the variables were less than 0.05. Therefore, the null hypothesis, Ho: $a_i = 0$, was rejected for all the variables based on P = 0.05 as the level of significance. Table 7.2 also presents the standardized and unstandardized coefficient values.

Table 7.1: Independent Variables for Metal Culverts

Independent Variable	Description	Unit	Range
Culvert Type (CT)	Corrugated Metal Pipe (CMP) Structural Steel Plate (SSP)	---	1-2 1= CMP 2= SSP
Age (AG)	Age of the Pipe	Years	6-80
pH	pH of water flowing through the pipe	---	2.8-8.8
Wall thickness (WT)	Pipe wall thickness	Inches	0.075-0.288
Abrasiveness (AB)	Presence of abrasive material (gravel, stones, or cobbles)	---	1-3 1=No 2=Possible 3= Yes
Flow Velocity (FV)	Flow velocity inside the pipe	---	1-4 1=Rapid (> 2fps) 2= Moderate (1-2 fps) 3= Slow (<1 fps) 4= No flow
Sediment Depth (SD)	Sediment depth inside the pipe	Inches	0-14
Cover Height (CH)	Height of backfill on the top of the pipe	Feet	1-64
ADT	Average Daily Traffic	Vehicle	430-67850
Rise (RI)	Rise or Diameter	Inches	24-180

Table 7.2: ODOT General Rating (GR) Model

Model Predictors	Un-standardized Coefficients		Standardized Coefficient	Significance (P)
	a	Std. Error	a_n	
Constant	7.314	1.328	0.00	0.000
Age (AG)	-0.049	0.017	-0.449	0.009
Rise(RI)	0.033	0.010	0.596	0.002
Culvert Type (CT)	-1.411	0.655	-0.374	0.043

[Note] Dependent variable = General Rating (GR).

The following equation summarizes the results from Table 7.2:

$$GR = 7.31 - 0.049(AG) + 0.033(RI) - 1.41(CT) \qquad \text{Eq. 7.5}$$

Table 7.3 shows the effect of each independent variable on the R^2 values. The culvert age had the most effect, followed by the rise and culvert type. As noted in the table, the resulting and adjusted R^2 values were 0.5 and 0.43, respectively.

Table 7.3: ODOT Metal Culverts R^2 Changes

Model Predictors	R	R^2	Adjusted R^2	R^2 Change
Const., Age	0.46	0.21	0.17	0.21
Const., Age, Rise	0.62	0.39	0.33	0.18
Const., Age, Rise, Culvert Type	0.71	0.5	0.43	0.11

Figure 7.1 plots the residuals against the predicted values of the general rating (GR). This plot shows neither trend nor extreme outliers (more than three standards deviations from zero). Figure 7.2 presents the histogram of the residuals, which reveals a reasonably adequate (not skewed) histogram. Thus, this model satisfies the normality assumption.

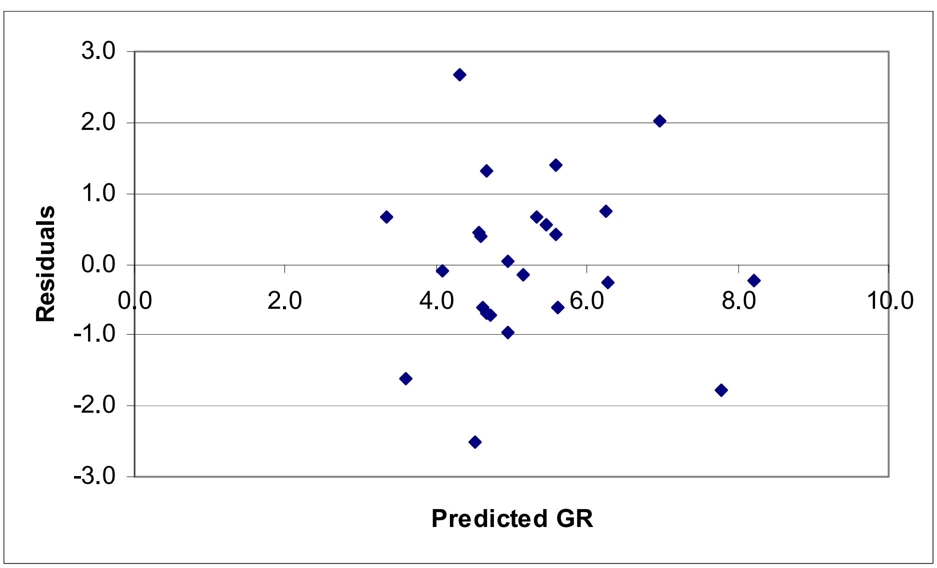


Figure 7.1: Residuals vs. Predicted GR for Metal Culverts (ODOT Rating System)

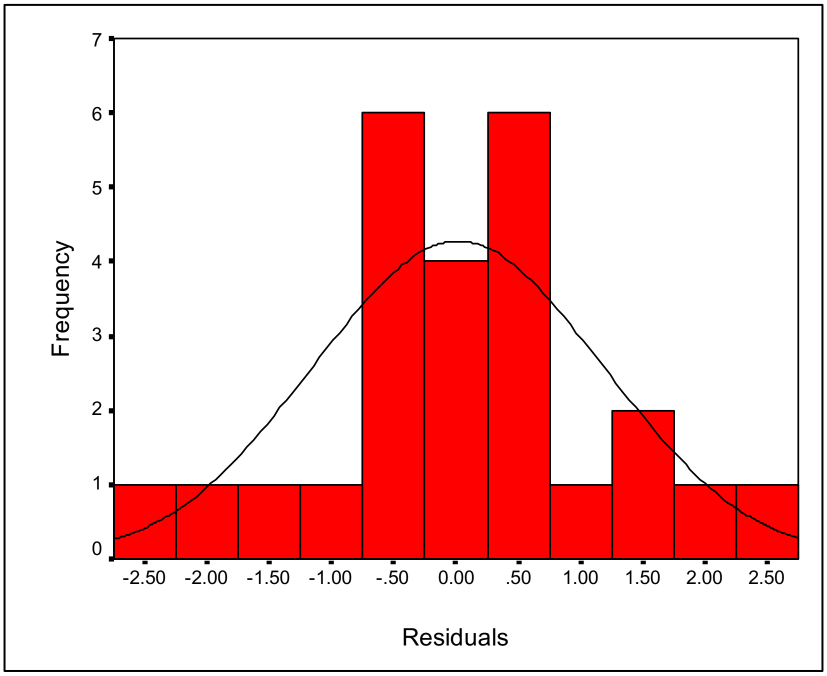


Figure 7.2: Frequency Bar Chart for Metal Culverts (ODOT Rating System)

7.6.1.2 Linear Regression Analysis of Metal Culvert Data Based on the Proposed Rating System

The proposed rating system provided more items and higher resolutions for the culvert field inspection process. For example, the system rated the metal surface conditions in the three regions (top, sides, invert) independently. The analysis was conducted based on the overall metal rating (OMR), which was dictated for each culvert by the lowest rating among the ratings that the all three regions received. This practice is consistent with the approach presented in the ODOT Culvert Management Manual (2003), which recommended that any item rating be based on the worst conditions. Culvert type, pH, abrasiveness, flow velocity, age, and rise were all significant predictors for the overall metal rating. Table 7.4 and Eq. 7.6 present the final modeling results.

Table 7.4: Proposed Overall Metal Rating Model

Model Predictors	Un-standardized Coefficients		Standardized Coefficient	Significance (P)
	a	Std. Error	a	
Constant	13.81	2.164	0.00	5.2E-06
Culvert Type (CT)	-1.69	0.562	-0.362	7.6E-03
pH	-0.54	0.205	-0.309	1.6E-02
Abrasiveness (AB)	-1.06	0.302	-0.532	2.5E-03
Flow Velocity (FV)	-0.91	0.36	-0.351	2.1E-02
Age (AG)	-0.04	0.018	-0.277	5.0E-02
Rise (RI)	0.05	0.009	0.671	8.6E-05

[Note] Dependant Variable = Overall Metal Rating (OMR).

OMR= 13.81-1.69(CT)-0.54(pH)-1.06(AB)-0.91(FV)-0.04(AG) + 0.05(RI) Eq. 7.6

The P-values for the variables were less than 0.05. Consequently, the null hypothesis Ho: $a_i = 0$, was rejected for all the variables based on P = 0.05 as the level of significance. Table 7.5 shows the changes in the R^2 and the effect of each independent variable on the R^2 values. The resulting and adjusted R^2 values were 0.81 and 0.75, respectively.

Table 7.5: Proposed Metal Culverts (OMR) R^2 Changes

Model Predictors	R	R^2	Adjusted R^2	R^2 Change
Const., Age	0.63	0.40	0.37	0.40
Const., Age, Rise	0.75	0.59	0.52	0.19
Const., Age, Rise, Abrasiveness	0.8	0.64	0.58	0.05
Const., Age, Rise, Abrasiveness, flow velocity	0.80	0.68	0.62	0.04
Const., Age, Rise, Abrasiveness, flow velocity, culvert type	0.86	0.74	0.67	0.06
Const., Age, Rise, Abrasiveness, flow velocity, culvert type, pH	0.91	0.81	0.75	0.07

The residuals plotted in Figure 7.3 show a scatter without any extreme outliers or trend presence. Figure 7.4 presents the histogram of the residuals. This reveals a reasonably adequate histogram. Thus, the model satisfies the normality assumption.

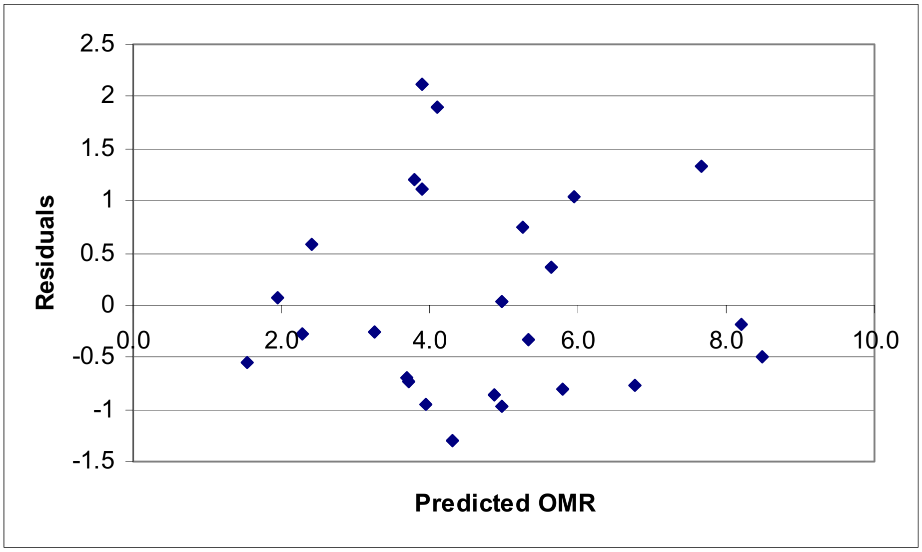


Figure 7.3: Residuals vs. Predicted OMR for Metal Culverts (Proposed Rating System)

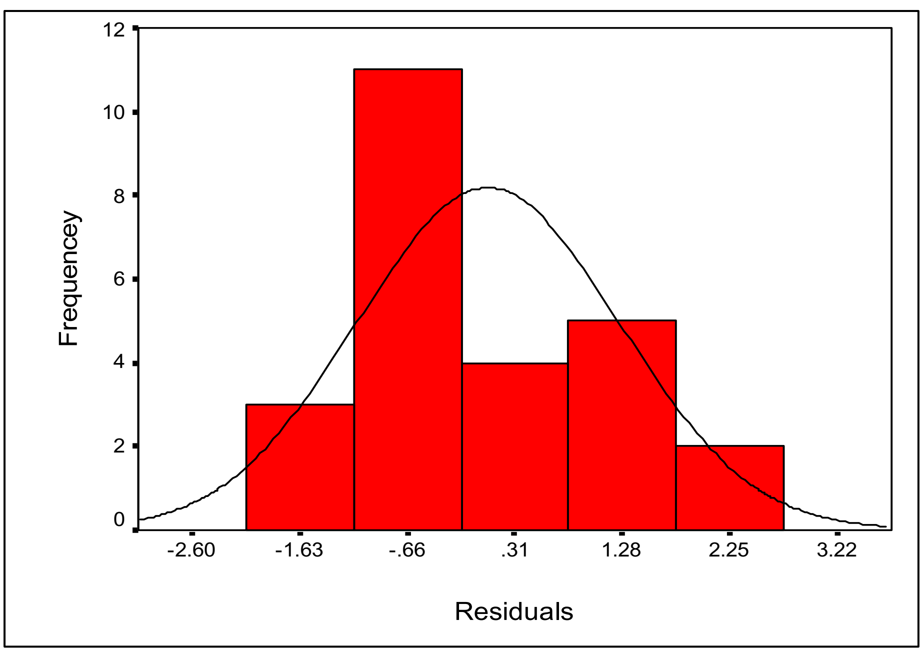


Figure 7.4: Frequency Bar Chart for Metal Culverts (Proposed Rating System)

7.6.2 Linear Regression Analysis of Concrete Culvert Data

This section presents the linear regression analysis results for the concrete culverts, based on both (ODOT, proposed) culvert rating systems. Table 7.6 presents a list of the independent variables used in the analysis, as well as their units, ranges, and symbols.

Table 7.6: Independent Variables for Concrete Culverts

Independent Variable	Description	Unit	Range
Age (AG)	Age of the Pipe	Years	1-80
pH	pH of water flowing through the culvert	-------	4.9-9
Wall thickness (WT)	culvert wall thickness	Inches	5.5-24
Abrasiveness (AB)	Presence of abrasive material (gravel, stones, or cobbles)	-------	1-3 1=No 2=Possible 3= Yes
Flow Velocity (FV)	Flow velocity inside the culvert	-------	1-4 1=Rapid (> 2fps) 2= Moderate (1-2 fps) 3= Slow (<1 fps) 4= No flow
Sediment Depth (SD)	Sediment depth inside the culvert	Inches	0-36
Cover Height (CH)	Backfill height on the top of the culvert	Feet	1-15
ADT	Average Daily Traffic	Vehicle	430-67850
Rise (RI)	Rise or Diameter	Inches	30-84

7.6.2.1 Linear Regression Analysis of Concrete Culvert Data Based on ODOT Rating System

The linear regression analysis was performed by using the General Rating (GR) as a dependant variable and all the independent variables listed in Table 7.6. The age, pH, and abrasiveness were significant independent variables for predicting the general rating

(GR) of the concrete culverts, based on the data collected by the ODOT rating system. Table 7.7 and Eq. 7.7 present the final modeling outcome.

As shown in Table 7.7, the P-values for the variables were less than 0.05. Therefore, the null hypothesis Ho: $a_i = 0$, was rejected for all the variables based on P = 0.05 as the level of significance.

Table 7.7: Concrete General Rating Model (ODOT Rating System)

Model	Un-standardized Coefficients		Standardized Coefficient a	Significance (P)
	a	Std. Error		
Constant	17.57	1.328	0.000	0.000
Age (AG)	-0.04	0.017	-0.52	0.007
pH	-1.23	0.010	-0.533	0.003
Abrasiveness (AB)	-2.01	0.655	-0.396	0.036

[Note] Dependent variable = General Rating (GR).

$$GR= 17.57-0.04(AG) - 1.23(pH)-2.01(AB) \qquad \text{Eq. 7.7}$$

Table 7.8 shows the changes in the R^2 value and the effect of each independent variable on the R^2 value. The resulting and adjusted R^2 value were 0.53 and the 0.45, respectively.

Table 7.8: Concrete Culverts R^2 Changes (ODOT Rating System)

Predictors	R	R^2	Adjusted R^2	R^2 Change
Const., Age	0.45	0.20	0.16	0.20
Const., Age, pH	0.67	0.41	0.35	0.21
Const., Age, pH, Abrasiveness	0.73	0.53	0.45	0.12

The residuals plotted in Figure 7.5 show a scatter without any extreme outliers or trend presence. Figure 7.6 presents a histogram of the residuals, which reveals a reasonably adequate histogram. Thus, this model satisfies the normality assumption.

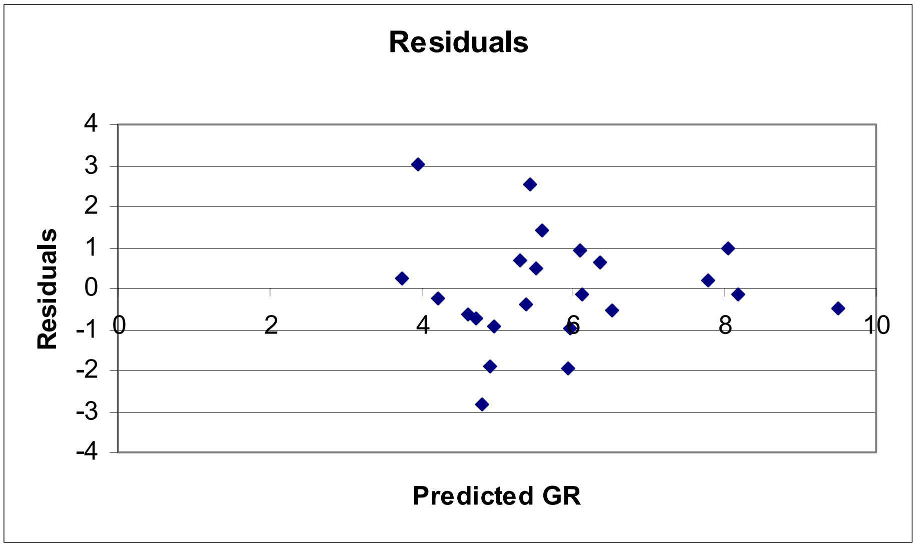


Figure 7.5: Residual vs. Predicted GR for Concrete Culverts (ODOT Rating System)

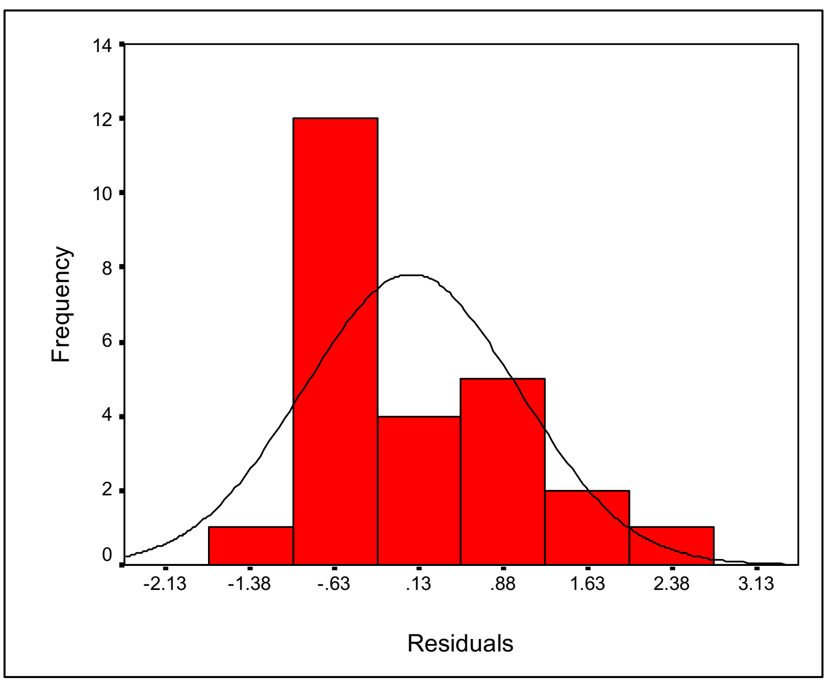


Figure 7.6: Frequency Bar Chart for Concrete Culverts (ODOT Rating System)

7.6.2.2 Linear Regression Analysis of Concrete Culvert Data Based on the Proposed Rating System

The proposed concrete culvert rating system was higher-resolutioned than the ODOT rating system, so that it could be used to assess the overall adequacy of the ODOT system. The analysis was conducted based on the overall concrete surface rating (OCSR), which is the lowest of the ratings that the three regions (top, sides, and invert) received. This treatment is consistent with the approach outlined in the ODOT Culvert Management Manual (2003), which recommended that the rating of any item be based on its worst conditions.

The linear regression analysis was performed by using the OCSR as a dependant variable and all the independent variables listed in Table 7.6. The age and pH were significant independent variables. The drainage flow abrasiveness did not surface as a significant variable due to a lack of data. Table 7.9 and Eq. 7.8 present the final modeling outcome.

Table 7.9: Concrete OCSR Rating Model (Proposed Rating System)

Model	Un-standardized Coefficients		Standardized Coefficients	Significance (P)
	a	Std. Error	a	
Constant	14.573	3.11	0.00	0.000
Age (AG)	-0.041	0.015	-0.469	0.013
pH	-0.945	0.423	-0.382	0.037

[Note] Dependent variable = Overall Concrete Surface Rating (OCSR).

$$OCR = 14.57 - 0.041(AG) - 0.945(pH) \quad \text{Eq. 7.8}$$

As shown in Table 7.9, P-values for the variables were less than 0.05. Consequently, the null hypothesis Ho: $a_i = 0$, was rejected for all the variables based on P = 0.05 as the level of significance. Table 7.10 shows the changes in the R^2 and the effect of each independent variable on the R^2 values. The resulting and adjusted R^2 values were 0.44 and 0.34, respectively.

Table 7.10: Concrete Culverts R^2 Changes (Proposed Rating System)

Model Predictors	R	R^2	Adjusted R^2	R^2 Change
Const., Age	0.55	0.30	0.27	0.30
Const., Age, pH	0.66	0.44	0.39	0.14

The residuals plotted in Figure 7.7 show a scatter without any extreme outliers or trend presence. The histogram of the residuals, shown in Figure 7.8, is reasonably adequate, not skewed. Therefore, the model satisfies the normality assumption.

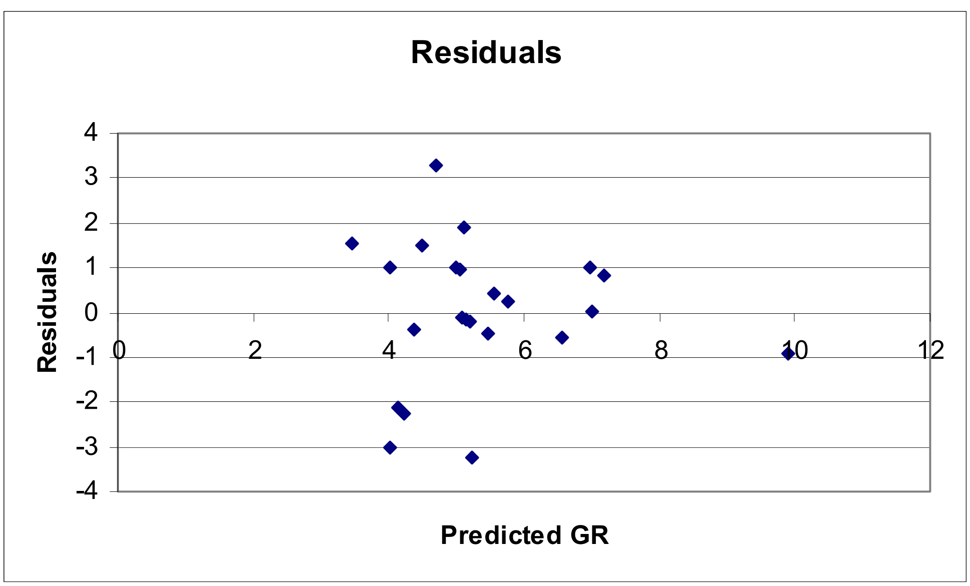


Figure 7.7: Residual vs. Predicted OCSR for Concrete Culverts (Proposed Rating System)

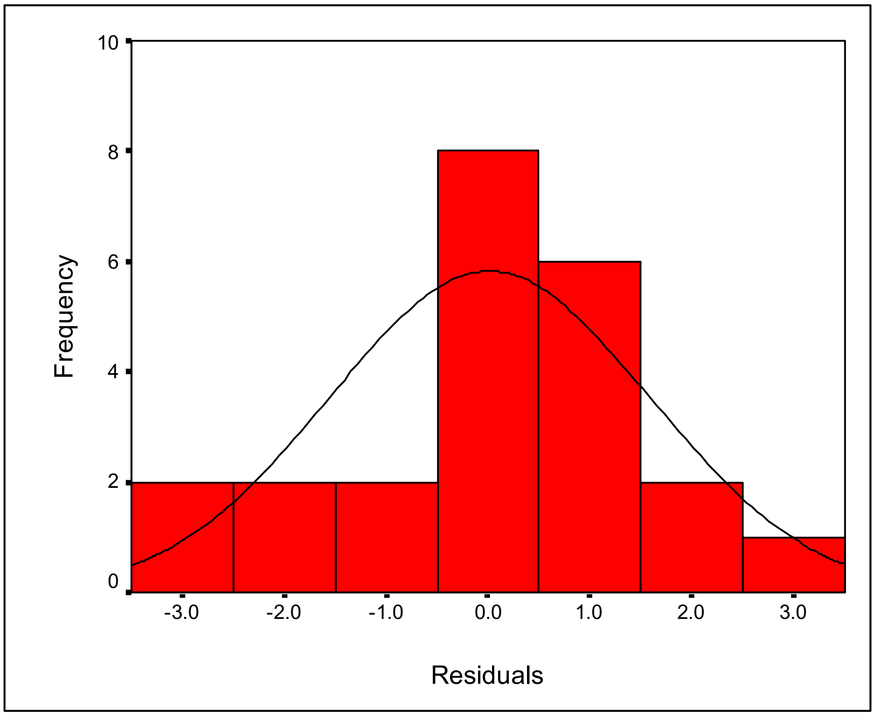


Figure 7.8: Frequency Bar Chart for Concrete Culverts (Proposed Rating System)

7.7 RESULTS OF NONLINEAR REGRESSION ANALYSIS

This section presents the results of the nonlinear regression analysis for concrete and metal culverts based on both rating systems.

7.7.1 Nonlinear Regression Analysis for Metal Culverts

Nonlinear regression analysis was performed by using both the ODOT and proposed rating systems. Age was the only significant independent variable to predict the GR for the ODOT rating system. The age, pH, and wall thickness were significant independent variables to predict the OMR in the proposed rating system. Table 7.11 and Equations 7.9 and 7.10 present the final results for both models.

Table 7.11 Metal Culverts Nonlinear Models

Rating system	Dependent Variable	Independent Variables	Coefficients		95% C.I* for a_n		R^2
			a_0	a_n	Lower	Upper	
ODOT	General Rating (GR)	Age	12.95	a_1= -0.25	-0.41	-0.09	0.25
Proposed	Overall Metal Rating(OMR)	Age	390.93	a_1=-0.43	-0.64	-0.23	0.51
		pH		a_2=-0.79	-1.40	-0.17	
		Wall Thick.		a_3=0.71	0.133	1.28	

*C.I= confidence Interval

$GR = 12.95(Age)^{-0.25}$ ODOT Rating System Eq. 7.9

$OMR = 390.93(Age)^{-0.43}(pH)^{-0.79}(Thick.)^{0.71}$ Proposed Rating System Eq. 7.10

The results of the nonlinear regression analysis for the metal culverts show that the proposed rating system detected more significant variables and had a higher value of R^2. The results also show that the culvert conditions may not decline at a constant rate over the years of service.

7.7.2 Nonlinear Analysis for Concrete Culverts

The nonlinear regression analysis was performed for concrete culverts by using both rating systems. The age was the only significant independent variable to predict the GR and OCSR in both rating systems. Table 7.12, Eq. 7.11, and Eq. 7.12 present the final outcome of the nonlinear modeling.

Table 7.12: Concrete Culverts Nonlinear Models

Rating system	Dependent Variable	Independent Variables	Coefficients		95% C.I* for a_n		R^2
			a_0	a_n	Lower	Upper	
ODOT	General Rating (GR)	Age	9.69	a_1= -0.14	-0.23	-0.05	0.26
Proposed	Overall Concrete surface Rating (OCSR)	Age	9.89	a_1= -0.17	-0.27	-0.07	0.31

*C.I= confidence Interval

$GR = 9.69(Age)^{-0.14}$ ODOT Rating System Eq. 7.11

$OCSR = 9.89(Age)^{-0.17}$ Proposed Rating System Eq. 7.12

The nonlinear regression analysis for the concrete culverts shows that the ODOT and proposed rating systems detected the same significant variable (age). The proposed rating system had a higher value for R^2. This analysis shows that the culvert conditions may not decline at a constant rate over the years of service. The rate of material degradation may be slow during the initial years and may start increasing once a certain minimum age is reached.

7.8 ASSESSMENT OF ODOT DURABILITY EQUATIONS

The ODOT Culvert Durability Study (1982) presented equations to predict metal rating as a function of age, water pH, wall thickness, and abrasion for two types of metal culverts CMP and SSP as shown in Equations 7.13 to 7.16.

CMP w/o abrasion $$Rating = \frac{41.71(age)^{0.271}}{(pH)^{0.677}(Thickness)^{0.474}}$$ Eq.7.13

CMP with abrasion $$Rating = \frac{45.71(age)^{0.359}}{(pH)^{0.802}(Thickness)^{0.466}}$$ Eq.7.14

SSP w/o abrasion $$Rating = \frac{8.53(age)^{0.215}(Thickness)^{0.045}}{(pH)^{1.25}}$$ Eq.7.15

SSP with abrasion $$Rating = \frac{4.05(age)^{0.211}(Thickness)^{0.007}}{(pH)^{0.696}}$$ Eq.7.16

The ODOT durability analysis was based on a rating scale of one to four (1-4), with the rating score of 1 being good and the rating score of 4 being critical. The new ODOT and proposed rating system are both based on a rating scale of zero to nine (0-9), with the rating score of 9 being excellent (like new), the rating score of 1 being very poor, and the rating score of 0 indicating a failure. In order to assess the reliability of the ODOT durability equations for the metal culverts inspected in the current study, it was necessary to convert the rating score based on the 0-9 scale to an equivalent rating score based on the 1-4 scale. Table 7.13 below presents the systematic conversion between the 0-9 scale and 1-4 scale.

Table 7.13: Conversion from 0-9 Scale to 1-4 Scale

Score in 0-9 Rating Scale	Equivalent Score in 1-4 Rating Scale
7, 8, 9	1 (Good)
5, 6	2 (Fair)
3, 4	3 (Poor)
0, 1, 2	4 (Critical)

Table 7.14 presents the data of the ODOT and proposed rating systems based on the (1-9), converted to the (1-4) rating system, and the predicted metal rating using the ODOT durability equations.

Table 7.14: Assessment of ODOT Durability Equations for Metal Culverts

Culvert No.	Culvert ID	Type	Abrasive Conditions	ODOT Rating System		Proposed Rating System		ODOT Durability Equations
				General Rating		Overall Metal Rating		
				(0-9) Scale	(1-4) Scale	(0-9) Scale	(1-4) Scale	(1-4) Scale
1	HOC-595-2.85	SSP	Yes	4	3	2	4	3
2	HOC-664-17.16	SSP	No	6	2	6	2	2
3	HOC-664-22.4	SSP	Yes	4	3	3	3	2
4	GAL-7-21.3	CMP	Yes	2	4	1	4	4
5	MEG-681-7.94	CMP	Yes	6	2	6	2	3
6	MEG-681-13.96	SPP	Yes	5	2	5	2	2
7	LIC-16-13.66	SPP	Yes	5	2	3	3	2
8	HOC-595-4.57	SPP	No	2	4	3	3	2
9	GUE-70-8.94	SPP	No	5	2	5	2	2
10	MUS-93-1.76	SPP	No	5	2	5	2	2
11	MAD-29-8.8	SPP	Yes	4	3	2	4	3
12	HIG-50-19.82	CMP	No	6	2	6	2	3
13	GUE-77-7.85	SPP	No	5	2	5	2	2
14	WAS-339-15.25	SPP	Yes	4	3	3	3	2
15	WAS-60-4.84	SPP	Yes	5	2	4	3	2
16	KNO-95-0.08	SPP	No	4	3	3	3	2
17	**JAC-124-17.12**	SPP	No	7	1	8	1	**5**
18	PIK-32-15.96	SPP	No	9	1	9	1	2
19	CLI-124-0.03	SSP	Yes	4	3	3	3	2
20	ADA-247-11.78	CMP	No	6	2	6	2	3
21	PAU-66-2.44	CMP	No	6	2	4	3	3
22	DEF-18-20.60	CMP	No	7	1	6	2	3
23	PUT-15-14.78	SSP	Yes	6	2	5	2	2
24	LAK-90-14.0	SSP	Yes	8	1	8	1	2
25	LAK-90-4.2	SSP	Yes	7	1	7	1	2

As shown in the table, the ODOT durability equations predicted the metal rating scores relatively closely under the ODOT and the proposed rating systems. The only exception occurred for Metal Culvert No. 17, for which the ODOT durability equation predicted a rating of 5 (above the upper rating limit).

7.9 RISK ASSESSMENT METHOD

This section proposes a simple yet comprehensive culvert risk assessment method. This method is based on the field inspection data, as well as the statistical analysis results. For either the ODOT or the proposed culvert rating system, the method takes the original average culvert rating score (total score divided by the number of rated items) and adjusts it by considering the culvert age, pH of drainage water, abrasiveness of the drainage flow, and the cover height (H) to rise or diameter (R) ratio. This last factor is incorporated here, because the risk to motorists tends to be greater when the H/R ratio is lower. This concept is presented in Eqs. 7.17 and 7.18:

$$AOR= M_1 * M_2 * M_3 * M_4 * (OAR) \qquad \text{for Metal \& Concrete Culverts} \qquad \text{Eq. 7.17}$$

$$AOR= M_4 * (OAR) \qquad \text{for Plastic Pipe Culverts} \qquad \text{Eq. 7.18}$$

where AOR= adjusted overall rating score; M_1= rating modifier due to culvert age; M_2= rating modifier due to water pH; M_3 = rating modifier due to abrasiveness of drainage flow; M_4= rating modifier due to H/R ratio; and OAR= original average rating score.

Linear form was utilized here for the ease of application and due to a lack of comprehensive data correlating the rate of culvert material deterioration over time. A similar but less comprehensive approach has been taken by the others to develop a culvert risk assessment model (McGrath and Beaver, 2003). The AOR score for the thermoplastic pipe culvert is adjusted by the H/R factor only, because the thermoplastic materials do not age like metals and concrete (more chemically stable) and that they are also more abrasion resistant.

Tables 7.15 (a) through (d) present proposed modifier values. The age modifier (M_1) values are based on the culvert age and rating analysis presented at the end of Chapter 6. Flow abrasiveness, pH, and the H/R ratio modifier (M_2, M_3, M_4) values are based on the results of statistical analysis and literature review. There was initially an idea to introduce the fifth modifier that is based on the ADT classifications of the roadway the culvert is associated with. However, this idea was abandoned because of its potentially controversial nature.

Table 7.15.(a): Value of Age Modifier

Culvert Age (yrs.)	Age Modifier Value	
	Concrete	Metal
Less than 20	1.0	1.0
20 - 40	0.95	0.9
40 -60	0.9	0.85
More than 60	0.85	0.8

Table 7.15.(b): Value of pH Modifier

pH	pH Modifier Value
More Than 7.0	1
5.0 - 7.0	0.95
Less Than 5.0	0.9

Table 7.15.(c): Value of Abrasiveness Modifier

Condition	Abrasiveness Modifier Value
Abrasive	0.9
Non-Abrasive	1.0

Table 7.15.(d): Value of H/R Ratio Modifier

H/R Ratio	H/R Ratio Modifier Value
More than 5	1
2.5 – 5	0.9
Less than 2.5	0.85

Maintenance immediacy and inspection course of action, proposed by NCHRP 251 (1982), is adopted here to specify recommended action for each Adjusted Overall Rating (AOR) value, as shown in Table 7.16. The OAR score is calculated by taking the average of the culvert ratings; ratings are different depending on the rating system (ODOT or the proposed), culvert type, and culvert shape. This will be explained in more detail in the following sections.

Table 7.16: Maintenance Immediacy Action (after NCHRP, 1982)

AOR	Maintenance Immediacy of Action	Inspection Course of Action
9	No repairs needed.	Note in inspection report only
8	No repairs needed. List specific items for special inspection during next regular inspection.	
7	No immediate plans for repair. Examine possibility of increased level of inspection.	
6	By end of next season - add to scheduled work.	
5	Place in current schedule - current season- first reasonable opportunity.	Special notification to superior is warranted.
4	Priority - current season – review work plan for relative priority – adjust schedule if possible.	
3	High priority- current season as soon as can be scheduled.	
2	Highest priority – discontinue other work if required – emergency basis or emergency subsidiary action if needed (post, one lane traffic, no trucks, reduce speed, etc.)	Notify superiors verbally as soon as possible and confirm in writing
1	Emergency actions required – reroute traffic and close.	
0	Structure is closed for repairs.	

7.9.1 Culvert Risk Assessment Based on ODOT Rating System

The OAR score for each metal culvert was calculated by taking the average of the culvert ratings for general rating (GR), culvert alignment (CA), seams and joint (SJ), and culvert shape (CS), as indicated by Eq. 7.19:

$$OAR = (GR + CA + SJ + CS)/4 \quad \text{for Metal Culverts} \quad \text{Eq. 7.19}$$

The AOR was calculated by adjusting the OAR due to the age, water pH, flow abrasiveness, and the H/R ratio modifiers, as shown by Eq. 7.17. Table 7.17 presents the risk assessment calculations for the metal culverts based on the ODOT rating system. The AOR was between 2 and 6. Based on Tables 7.17 and 7.16, maintenance immediacy action for Metal Culverts No.3 and 16 are highest and high priority, respectively. The AOR for the rest of the culverts were between 4 and 6, and their maintenance immediacy actions were between 4 (priority - current season) and 6 (by end of next season - add to scheduled work). It is interesting to note that for almost half of the metal culverts the AOR was the same as the lowest of the four (GR, CA, CS, SJ) rating scores.

Table 7.17: Metal Culverts Risk Assessment Based on ODOT Rating System

No	Culvert ID	GR	CA	CS	SJ	OAR	AOR
1	HOC-595-2.85	4	8	7	7	7	4
2	HOC-664-17.16	6	8	8	8	8	5
3	HOC-664-22.4	4	3	3	2	3	2
4	GAL-7-21.3	2	3	NA*	2	NA*	NA*
5	MEG-681-7.94	6	8	5	7	7	4
6	MEG-681-13.96	5	8	8	7	7	4
7	LIC-16-13.66	5	6	7	7	6	4
8	HOC-595-4.57	2	7	6	8	6	4
9	GUE-70-8.94	5	9	3	8	6	6
10	MUS-93-1.76	5	8	4	6	6	4
11	MAD-29-8.8	4	8	6	7	6	4
12	HIG-50-19.82	6	8	7	7	7	6
13	GUE-77-7.85	5	8	6	7	7	6
14	WAS-339-15.25	4	8	8	8	7	4
15	WAS-60-4.84	5	8	5	5	6	4
16	KNO-95-0.08	4	6	3	4	4	3
17	JAC-124-17.12	7	7	5	7	7	4
18	PIK-32-15.96	9	8	6	7	8	6
19	CLI-124-0.03	4	7	7	6	6	4
20	ADA-247-11.78	6	8	6	7	7	5
21	PAU-66-2.44	6	8	5	7	7	5
22	DEF-18-20.60	7	7	4	8	7	4
23	PUT-15-14.78	6	8	6	8	7	4
24	LAK-90-14.0	8	9	8	8	8	5
25	LAK-90-4.2	7	8	8	8	8	6

*NA= Not Available.

The OAR calculation method for the concrete culverts depended on the type of concrete culvert. For circular pipe and elliptical concrete culverts, the OAR was calculated by taking the average of the culvert ratings under general rating (GR), culvert alignment (CA), and joints (J), as shown by Eq. 7.20:

$$OAR = (GR + CA + J)/3 \qquad \text{for Concrete Pipe \& Elliptical Culverts} \qquad \text{Eq.7.20}$$

The OAR score for the slab-on-top and box culverts was calculated by taking the average of the culvert ratings under general rating (GR), culvert alignment (CA), slab (S), and abutment (A), as shown by Eq. 7.21:

$$OAR = (GR + CA + S + A)/4 \qquad \text{for Concrete Slab on Top \& Box Culverts} \qquad \text{Eq.7.21}$$

The AOR was calculated by adjusting the OAR due to age, water pH, flow abrasiveness, and the H/R ratio, according to Eq. 7.17. Tables 7.18.(a) and 7.18.(b) present the calculation results among the concrete pipe and elliptical culverts, and concrete slab-on-top and box culverts respectively, based on the ODOT rating system.

Table 7.18. (a): Pipe and Elliptical Concrete Culverts Risk Assessment Based on ODOT Rating System

No.	Culvert ID	GR	CA	J	OAR	AOR
8	LIC-70-13.52	6	6	6	6	5
14	ATH-278-0.25	9	8	8	8	6
16	HIG-124-21.75	9	8	8	8	6
19	HAN-224-6.84	7	6	4	6	5
22	GRE-380-5.03	8	6	5	6	5
23	CUY-480-0.75	5	8	7	7	5
24	CUY-422-15.2	8	7	6	7	6

Table 7.18.(b): Slab on Top and Box Concrete Culverts Risk Assessment Based on ODOT Rating System

No.	Culvert ID	GR	CA	S	A	OAR	AOR
1	HOC-216-2.00	8	9	6	7	8	5
2	HOC-78-1.05	6	9	5	6	7	4
3	HOC-216-3.25	7	9	7	7	8	5
4	HOC-216-3.43	NA*	NA*	NA*	NA*	NA*	NA*
5	MRG-78-11.34	7	9	7	7	8	5
6	MRG-78-24.40	4	9	4	5	6	4
7	VIN-56-6.85	6	9	6	7	7	5
9	MAD-29-11.37	5	8	4	6	6	4
10	MAD-142-4.30	4	9	3	4	5	4
11	CLI-28-7.84	4	8	4	3	5	3
12	MEG-338-16.42	2	5	2	2	3	2
13	COS-93-11.54	4	8	5	4	5	4
15	FAY-753-2.09	3	8	2	4	4	3
17	PIK-335-5.18	6	9	6	6	7	5
18	PUT-189-10.5	4	7	7	4	6	4
20	WAY-103-1.06	4	4	7	4	5	4
21	BUT-126-2.58	4	6	6	6	6	4
25	MRG-60-19.95	7	9	7	7	8	5

*NA = Not Available

The adjusted overall rating (AOR) for the concrete culverts ranged from 2 to 6, based on the ODOT rating system. Applying Tables 7.16 to Tables 7.18.(a), and 7.18.(b), Concrete Culvert No.12 had the highest priority maintenance immediacy action. Concrete Culvert Nos.11 and 15 rated high priority of maintenance immediacy actions. The AOR scores for the rest of the culverts were between 4 and 6, and their maintenance immediacy actions varied between 4 (priority - current season) and 6 (by end of next season - add to scheduled work). It is interesting to note that for almost half of the concrete culverts the AOR was the same as the lowest of the individual (GR, CA, S/J, A) rating scores.

The OAR for thermoplastic pipe culverts was calculated by taking the average of the ratings under general rating (GR), culvert alignment (CA), culvert shape (CS), and joints (J), as indicated by Eq. 7.22:

OAR = (GR + CA + CS + J)/4 for Thermoplastic Pipe Culverts Eq. 7.22

The AOR was calculated by adjusting the OAR due to the H/R ratio, as shown by Eq. 7.18. Table 7.19 presents the risk assessment calculation results for the plastic culverts, based on the ODOT rating system. AOR values were between 6 and 9. It is interesting to note that for almost half of the concrete culverts the AOR was the same as the lowest of the individual (GR, CA, CS, J) rating scores. According to Table 7.16, their maintenance immediacy actions were between 6 (by end of next season - add to scheduled work) and 9 (no repairs needed).

Table 7.19: Plastic Pipe Culvert Risk Assessment Based on ODOT Rating System

No	Culvert ID	GR	CA	CS	J	OAR	AOR
1	FAI-33b-446+92	9	6	6	7	7	NA*
2	MEG-124-30.17	8	7	6	8	7	6
3	PER-13-11.14	9	7	6	7	7	6
4	FAI-33b-587+96	9	9	8	9	9	8
5	FAI-22-17+20	9	6	9	8	8	8
6	FAI-33b-96	9	9	9	9	9	8
7	FAI-33b-86	9	7	6	8	8	7
8	HOC-327-2.7	9	6	5	8	7	6
9	NOB-145-3.59	8	7	6	8	7	6
10	FAI-33-488+07	9	9	9	9	9	9

* NA= Not Available.

7.9.2 Culvert Risk Assessment Based on Proposed Rating System

For the proposed rating system, the OAR score for the metal culverts was calculated by taking the average of the culvert ratings for metal plate (MP), horizontal alignment (HA), seams and joint (SJ), culvert shape (CS), slope and settlement (SS), and culvert deflection (CD), as shown by Eq. 7.23:

$$OAR = (MP + HA + SJ + CS + SS + CD)/6 \qquad \text{for Metal Culverts} \qquad \text{Eq.7.23}$$

The AOR was calculated by adjusting the OAR due to age, water pH, flow abrasiveness, and the H/R ratio, as indicated by Eq. 7.17. Table 7.17 presents the risk assessment calculation results for metal culverts, based on the proposed rating system. Adjusted overall rating (AOR) for the metal culverts was between 2 and 6. It is noted that for only about ¼ of the metal culverts the AOR was equal to the lowest of the individual rating scores. Based on Tables 7.16 and 7.20, Metal Culvert Nos. 3 and 7 yielded the highest and high priority for maintenance immediacy actions, respectively. The rest of the culverts' adjusted overall rating (AOR) scores were between 4 and 6. Thus, their maintenance immediacy actions fell between 4 (priority - current season) and 6 (by end of next season - add to scheduled work).

Table 7.20: Metal Culverts Risk Assessment Based on Proposed Rating System

No.	Culvert ID	MP	HA	SJ	CS	SS	CD	OAR	AOR
1	HOC-595-2.85	2	8	7	7	7	7	6	4
2	HOC-664-17.16	6	8	8	7	7	7	7	5
3	HOC-664-22.4	3	3	1	2	3	5	3	2
4	GAL-7-21.3	1	2	1	NA*	2	NA*	NA*	NA*
5	MEG-681-7.94	6	8	6	5	7	5	6	4
6	MEG-681-13.96	5	8	7	7	8	7	7	4
7	LIC-16-13.66	3	7	5	7	6	6	6	3
8	HOC-595-4.57	3	8	5	8	6	8	6	4

* NA= Not Available.

Table 7.20: Metal Culverts Risk Assessment Based on Proposed Rating System (cont'd)

No.	Culvert ID	MP	HA	SJ	CS	SS	CD	OAR	AOR
9	GUE-70-8.94	5	8	8	6	6	4	6	6
10	MUS-93-1.76	5	8	6	5	8	5	6	4
11	MAD-29-8.8	2	8	7	7	8	7	7	4
12	HIG-50-19.82	6	8	7	7	7	7	7	6
13	GUE-77-7.85	5	8	6	7	7	7	7	6
14	WAS-339-15.25	3	8	7	8	8	8	7	4
15	WAS-60-4.84	4	8	6	5	8	5	6	4
16	KNO-95-0.08	3	6	4	5	8	5	5	4
17	JAC-124-17.12	8	8	8	5	7	5	7	5
18	PIK-32-15.96	9	7	7	8	8	8	8	6
19	CLI-124-0.03	3	8	5	7	6	7	6	4
20	ADA-247-11.78	6	8	5	7	8	7	7	5
21	PAU-66-2.44	4	8	8	7	8	7	7	5
22	DEF-18-20.60	6	8	6	6	6	6	6	4
23	PUT-15-14.78	5	8	8	8	8	8	8	5
24	LAK-90-14.0	8	8	8	8	9	8	8	5
25	LAK-90-4.2	7	8	7	8	8	8	8	6

* NA= Not Available.

The OAR score for the concrete pipe and elliptical concrete culverts was calculated by taking the average of the rating scores under culvert material (CM), horizontal alignment (HA), slope and settlement (SS), and joints (J), as specified in Eq. 7.24. The OAR score for the concrete slab-on-top and box culverts was calculated by taking the average of the rating scores under culvert material (CM), slope and settlement (SS), and horizontal alignment (HA), as shown in Eq. 7.25:

$$OAR = (CM + HA + SS + J)/4$$ for Concrete Pipe & Elliptical Culverts Eq.7.24

$$OAR = (CM + SS + HA)/3$$ for Concrete Slab on Top & Box Culverts Eq.7.25

The AOR score for the concrete culverts was then calculated by adjusting the OAR due to the age, water pH, flow abrasiveness, and the H/R ratio modifiers, as shown in Eq. 7.17. Tables 7.21.(a) and 7.21.(b) present the risk assessment calculation results for the concrete pipe and elliptical culverts, and concrete slab-on-top and box culverts based, using the data collected through the proposed rating system.

Table 7.21.(a): Pipe and Elliptical Concrete Culverts Risk Assessment Based on Proposed Rating System

No.	Culvert ID	CM	HA	J	SS	OAR	AOR
8	LIC-70-13.52	6	7	7	6	7	6
14	ATH-278-0.25	6	6	6	6	6	5
16	HIG-124-21.75	8	8	6	6	7	5
19	HAN-224-6.84	6	8	7	8	7	6
22	GRE-380-5.03	8	8	8	7	8	7
23	CUY-480-0.75	9	8	7	7	8	6
24	CUY-422-15.2	8	9	8	9	9	7

Table 7.21.(b): Slab on Top and Box Concrete Culverts Risk Assessment Based on Proposed Rating System

No.	Culvert ID	CM	SS	HA	OAR	AOR
1	HOC-216-2.00	7	9	8	8	6
2	HOC-78-1.05	5	9	8	7	5
3	HOC-216-3.25	5	8	8	7	5
4	HOC-216-3.43	NA*	NA*	8	NA*	NA*
5	MRG-78-11.34	5	9	8	7	5
6	MRG-78-24.40	5	7	8	7	5
7	VIN-56-6.85	6	9	8	8	6
9	MAD-29-11.37	6	8	8	7	5
10	MAD-142-4.30	5	8	8	7	5
11	CLI-28-7.84	1	8	8	6	4
12	MEG-338-16.42	2	4	8	5	3
13	COS-93-11.54	4	8	8	7	5
15	ATH-278-0.25	2	8	8	6	4
17	PIK-335-5.18	6	9	8	8	6
18	PUT-189-10.5	5	8	7	7	5
20	HAN-224-6.84	2	5	8	5	4
21	WAY-103-1.06	4	5	7	5	4
25	BUT-126-2.58	7	9	9	8	6

*NA= Not Available

The adjusted overall rating (AOR) for the concrete culverts varied between 3 and 6. Results presented in the two tables show that for almost half of the concrete culverts the AOR was equivalent to the lowest of the individual rating scores. According to Table 7.16, Concrete Culvert No.12 had a high priority of maintenance immediacy action. The rest of the culverts' adjusted overall rating scores ranged between 4 and 6. Thus, their maintenance immediacy actions varied between 4 (priority - current season) and 6 (by end of next season - add to scheduled work).

The OAR score for the thermoplastic pipe culverts was calculated by taking the average of the culvert rating scores under material rating (cracking and buckling = CB), horizontal alignment (HA), seams and joints opening (SJO), seams and joints cracking (SJC), shape observation deflection (DE), shape observation distortion (DI), and slope and settlement (SS), as shown in Eq. 7.26:

$$OAR = (CB + HA + SJO + SJC + DE + DI + SS)/7 \quad \text{for Plastic Pipe Culverts} \quad \text{Eq.7.26}$$

The AOR score was then calculated by adjusting the AOR by applying the H/R ratio modifier, as indicated by Eq. 7.18. Table 7.22 presents the risk assessment calculation results among the thermoplastic pipe culverts, using the data collected through the proposed rating system. The AOR for the thermoplastic pipe culverts, based on the proposed rating system, ranged between 5 and 9. For only one of the ten thermoplastic pipe culverts, the AOR score was equal to the lowest of the inspection rating scores. According to Table 7.16, their maintenance immediacy actions were between (place in current schedule - current season- first reasonable opportunity) and (no repairs needed).

Table 7.22: Plastic Pipe Culverts Risk Assessment Based on Proposed Rating System

No.	Culvert ID	SJO	SJC	DE	DI	CB	SS	HA	OAR	AOR
1	FAI-33b-446+92	8	5	5	4	7	9	7	8	NA*
2	MEG-124-30.17	8	5	6	6	2	6	6	8	5
3	PER-13-11.14	8	5	6	5	6	8	7	8	6
4	FAI-33b-587+96	9	6	6	9	9	9	8	9	7
5	FAI-22-17+20	9	9	8	9	7	9	9	9	9
6	FAI-33b-96	9	9	9	9	9	9	9	9	8
7	FAI-33b-86	8	9	9	9	7	8	7	8	7
8	HOC-327-2.7	9	9	9	9	6	7	8	8	7
9	NOB-145-3.59	9	3	6	8	5	7	7	9	6
10	FAI-33-488+07	9	5	6	9	7	9	8	9	8

* NA= Not Available.

Comparisons between Tables 7.17 and 7.20 for the metal culverts show that the adjusted overall rating (AOR) scores were nearly identical between the ODOT and the proposed metal culvert rating systems. A small discrepancy was detected for only four metal culverts (Metal Culvert Nos. 7, 16, 17, and 23). In each of these cases, the AOR based on the proposed rating system was larger than the AOR based on the ODOT rating system by 1. Comparisons between Tables 7.18.(a) and 7.21.(a) for the concrete pipe and elliptical culverts show that the adjusted overall rating (AOR) scores were similar between the ODOT and the proposed concrete culvert rating systems. For four of the seven culverts listed in these tables, the AOR based on the proposed rating system was larger than the AOR based on the ODOT rating system by 1. For one of the cases, the AOR based on the proposed method was larger than the AOR based on the ODOT rating system by 2. For two of the culverts, the AOR based on the proposed rating system was lower than the AOR based on the ODOT rating system by 1. Comparisons between Tables 7.18.(b) and 7.21.(b) for the concrete slab-on-top and cured-in-place box culverts show that the adjusted overall rating (AOR) scores were similar between the ODOT and the proposed concrete culvert rating systems. For four of the eighteen culverts listed in these tables, the AOR based on the proposed rating system was the same as the AOR based on the ODOT rating system. For thirteen of the cases, the AOR based on the proposed method was larger than the AOR based on the ODOT rating system by 1. Comparisons between Tables 7.19 and 7.22 for the thermoplastic pipe culverts show that the adjusted overall rating (AOR) scores were very similar between the ODOT and the proposed thermoplastic pipe culvert rating systems. For three of the ten cases, the AOR based on the ODOT rating method was higher than the AOR based on the proposed rating method by 1. For two cases, the outcome was reversed (i.e., the AOR based on the ODOT rating method higher than the AOR based on the proposed rating method by 1). And, for four cases, the AOR scores were identical between the ODOT and proposed methods. These discussions point out that the ODOT culvert rating systems are basically sound, and its version for the metal culverts may be slightly conservative.

CHAPTER 8: CULVERT MAINTENANCE & REPLACEMENT METHODS

8.1 INTRODUCTION

The Ohio Department of Transportation (ODOT) has responsibility for approximately 110,000 culverts statewide. The shear number indicates that not only should they be inspected, but also some common, standard means to repair or replace the deficient structures should be established. Large diameter culvert replacement projects can easily cost $250,000 for an uncomplicated open trench style construction. This does not include design or construction administration costs, or the indirect costs incurred by the public caused by road closures. ODOT does not have the funding capability to replace all the deficient culverts without looking at other more cost effective options.

In order to have an efficient culvert repair and replacement program requires three basic steps. The first step is developing a complete inventory and inspection program. Next, the data must be evaluated to determine the best culvert repair, rehabilitation and replacement program. Finally, the program must be put into place.

Chapter 4, along with ODOT's Culvert Management Manual covers the requirements for a good inventory and inspection program. The data collected from the inventory and inspections needs to be incorporated into the District and county work plans. Culvert failures, especially large diameter, can be disastrous. Small diameter culvert collapses can cause significant drainage issues that lead to pavement distress.

This chapter, along with complete inspections, is intended to aid the district program manager in determining a cost effective culvert program. The best program will be a combination of force account projects and construction contract projects. Each district should assess their availability of labor, equipment, and expertise; then, decide on the best overall culvert program.

Section 8.2 of this chapter presents several items to be considered in determining the best treatment for deficient culverts. It also includes a table of options to guide the program manager. Section 8.3 is designed for the program manager, designer, and construction personnel. It depicts the uses, resources, methods, limitations, and considerations for many of the more hopeful innovations. Other, less common, options are also briefly discussed. Appendix G includes sample specifications and plan sheets for the most promising techniques.

Overall, this chapter is devoted to exploring a variety of options for culvert barrel maintenance, rehabilitation and replacement. It is also the intent to highlight strengths, weaknesses, and design considerations for each type of treatment presented.

8.2 CHOOSING COUNTERMEASURES

Different countermeasures are available for fixing different types of problems. Some options will provide structural repairs, while others will extend service life. It is important to consider the strengths, weaknesses, and limitations of each viable option before making a final decision on the treatment selected.

To determine the best countermeasure requires that a good inventory and inspection program be in place. Most likely the inspection and inventory has yielded a list of locations that are potentially problems. Solving the problem is a three-step process: 1) Know the problem, 2) Know the cause of the problem and 3) Find the fix.

Fixing the problem without fixing the cause of the problem will only allow it to reemerge. You must fix both the problem and the cause of the problem. The following pages highlight problems and possible causes. It provides a list of items to check to help determine the cause of the problem and provides guidance in determining an appropriate countermeasure to address both the problem and its source.

Occasionally, it may only be feasible to address the problem, but not the cause. This is reality, and should be recognized. When this does happen, more frequent inspections may be required to check on the status of the source of the problem.

8.2.1 Considerations Involved in Determining Treatments

To adequately determine an appropriate repair, rehabilitation or replacement the culvert site must be investigated both in the office and in the field. It is important to look not only at today's issues, but also what could reasonably be expected in the future. Just as engineers consider increased traffic in pavement designs, changes in land use affect hydrology. Changes in traffic volumes may affect the loading on the structure. This is especially the case for culverts under minimal fill. As the fill gets deeper, the impact of traffic loading decreases. Another key consideration is anticipating future repairs or rehabilitation options. If the current problem is addressed now, will there be viable options to 'fix' it again? A good program manager will always be looking toward the future, and considering what the next project may require. Existing data should be reviewed before a field review is scheduled. Basic data should be drainage area, soil type, storm data, traffic data, expected land use changes, and existing structure information such as age, type, and maintenance history.

Other considerations should also be design standards and environmental limitations. For instance, ODOT requires that culverts on new alignments be designed to allow for a natural streambed and that culverts under sixteen ft (4.9 m) of fill be designed one size larger to allow for future repair.

During the field review, several items should be checked. In addition, pictures should be taken at inlet, outlet, upstream, downstream, within the culvert (if possible), along with any other areas of interest. Items to be checked should include, but not be limited to stream velocity, size and type of bedload, ph levels, condition of culvert, types of deficiencies, signs of distress, upstream and downstream culverts, debris in channel, channel shape and direction, clear zones, erosion, vegetation, culvert shape, scour holes, headwalls, wingwalls, sags in guardrail, cracks or dips in pavement and anything else that can be noticed during the field review. The available workspace around the culvert should be noted, as some types of repairs require a larger footprint than others.

The primary intent of the field review is to determine the extent of the problem and the source of the problem.

8.2.2 Table of Options

Once the underlying problem has been determined the various options need to be evaluated. The following Table of Options is a summary of different types of culvert barrel deficiencies and treatments.

Table 8.1: Different Culvert Barrel Deficiencies and Repair Options

Deficiency	Possible Repair Options
Joint Misalignment	Repair sleeves; CIPP; Fold & form Lining; Open-cut Replacement.
Joint Infiltration/Joint Defects	Cement grouting voids; Chemical grouting voids; Repair sleeves; Concrete (Gunite) lining; Sliplining; CIPP; Pipe bursting; Fold & form lining; Open-cut replacement.
Voids Behind Culvert Barrel	
Invert Deterioration	Concrete paving of invert; Steel plating; Concrete (Gunite) lining; Sliplining; CIPP; Fold & form lining; Open-cut replacement.
Cracking	Chemical grouting; Cement grouting; Concrete (Gunite) lining; Sliplining; CIPP; Pipe bursting; Fold & form lining; Open-cut replacement.
Rotted Timber Members	Timber bracing & repair; Sliplining; CIPP; Open-cut replacement.
Shape Distortion	Sliplining; CIPP; Fold & form lining; Open-cut replacement.
Missing Mortar in Masonry Culverts	Masonry repointing; Concrete (Gunite) lining; Sliplining; CIPP; Fold & form lining; Open-cut replacement.
Insufficient Flow Capacity	CIPP; Sprayable epoxy coating; Concrete (Gunite) lining; Pipe bursting; Fold & form lining; Open-cut replacement.
Corrosive and Abrasive Environment	Sprayable expoxy coating; Bituminous coating; Aluminumizing; Concrete (Gunite) lining; Painting culvert interior; Sliplining; CIPP; Fold & form lining; Open-cut replacement.
Spalling of Concrete Surfaces	Concrete (Gunite) lining; Sliplining; CIPP; Pipe bursting; Fold & form lining; Open-cut replacement.

The cost of different treatments is also important in determining the best use of resources. The following chart is based on about 200 projects from municipalities and is from an article in Trenchless Technology, *Costs of Trenchless Projects*, April 2003, by Jack Q. Zhao and Balvant B. Rajani. It can be used as a guide in evaluating costs of various options.

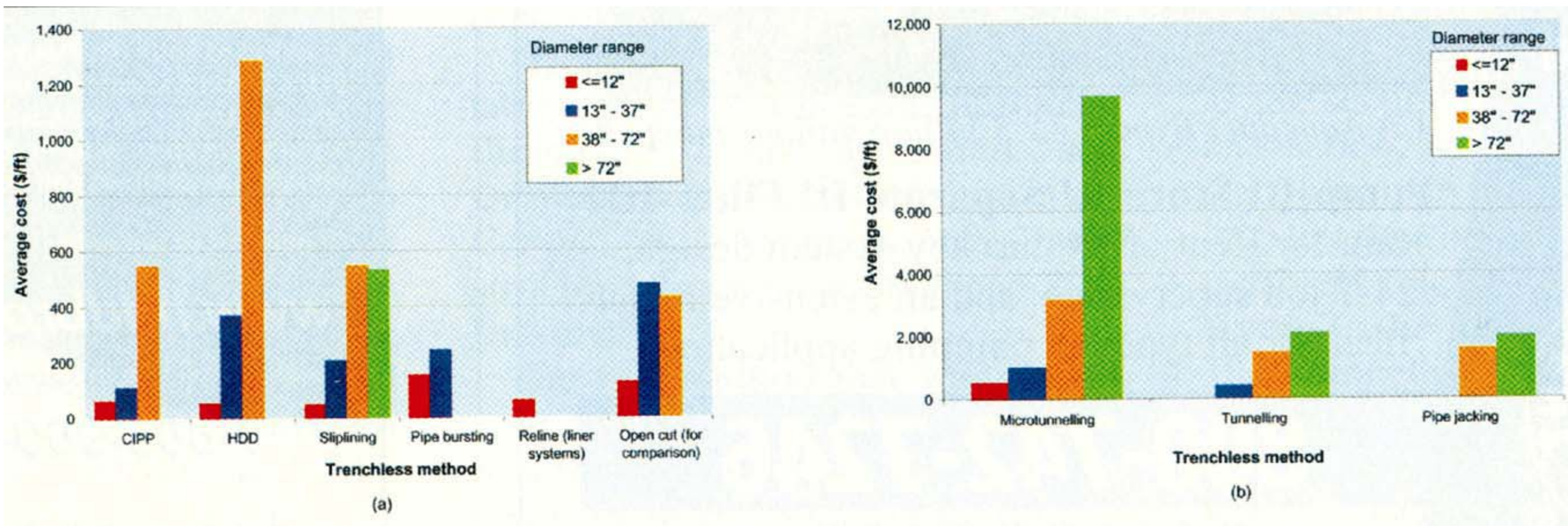


Figure 8.1: Average Cost Per Foot for Various Trenchless Technologies

8.3 CULVERT BARREL MAINTENANCE AND REPLACEMENT TECHNIQUES

For purposes of this document, replacement includes any treatments that create a structurally new barrel. Maintenance and rehabilitation includes treatments to the barrel that may add structural integrity, but does not replace the structural need of the original barrel.

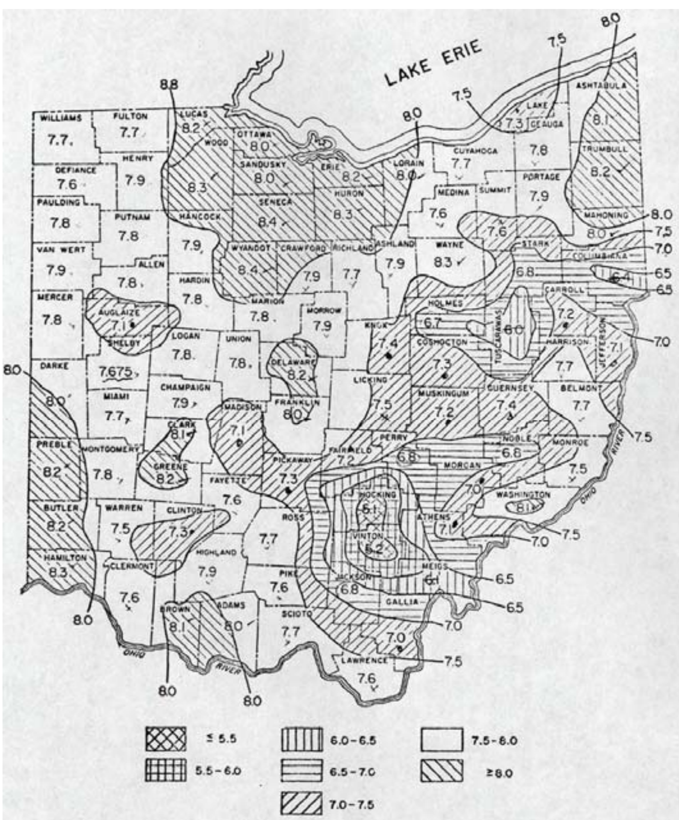
8.3.1 Culvert Barrel Maintenance and Rehabilitation Techniques

Any good infrastructure program requires a balance between funds available and needs. To preserve the system in the best overall condition a combination of maintenance and replacement projects is necessary. Due to financial constraints, it will not always be possible to replace culverts even when justified; it may be necessary to extend the life through rehabilitation and maintenance. At other times, it will be fiscally responsible to extend the service life of a culvert through appropriately selected maintenance and rehabilitation treatments. This section is committed to highlighting options for the maintenance and rehabilitation of the existing culvert system.

8.3.1.1 Invert Replacement and Repair

Inverts of culverts deteriorate for various reasons. Primarily they deteriorate because of abrasion or corrosion. Abrasive forces are created from the bedload moving through the culvert. According to the Federal Highway Administration, Culvert Repair Practices Manual stream velocities based on 2-5 year storms should be checked. Velocities greater than 15 ft/sec (4.5 m/sec) are undesirable, and the repair should include a means to dissipate the flow. Flows below 5 ft/sec (1.5 m/sec) are good. The bedload should be considered also. The size, shape, and hardness will affect the rate of deterioration. This is especially important to consider in the mid range of velocities (5 ft/sec – 15 ft/sec or 1.5 m/sec sec – 4.5 m/sec). The hardness of the natural streambed material should be compared to the hardness of the invert material. This should be considered in any concrete mix designs that are intended to protect the invert.

Corrosive forces can be caused by an imbalance in ph levels, soil resistivity, sulfate levels or industrial runoff. In Ohio, the most significant corrosive factor is ph level. Ph levels between 5.5 and 8.5 are considered neutral. Ph levels less than 5.5 are acidic and are frequently found in mine areas, as shown below.



From Ohio Culvert Durability Study, 1982 by J. Hurd, D. Meacham and W. Shisler

Figure 8.2: Typical Ph Values Found in Ohio

Ph levels greater than 8.5 are alkaline and can be found in some areas with high fertilizer usage. Acidic water corrodes steel pipe; while alkaline water affects aluminum pipe. Before the invert problem is remedied, the source of the problem must be determined, and the appropriate materials used to repair the invert.

If the invert of the culvert is damaged or worn away, a structural repair is necessary. The cross section of lost material will need to be replaced. This can be accomplished by adding a mat of reinforcing bars and wire mesh or adding sections of structural steel plate materials. Either way, the designer and installer need to allow for attachment to the existing structure to reestablish the hoop strength of the culvert.

The most frequently used type of invert replacement is concrete paving. The outcome of this type of work is highly dependent on the skill of the installer. In the first photo below the invert-paving job was poorly constructed. It allows for ponding in the pipe, flow behind the paved invert, and does not cover the bottom 1/3 of the pipe. In contrast, the second photo is a good invert paving job.

Figure 8.3: Example of Poor Invert Paving

Figure 8.4: Example of Good Invert Paving

Utilizing skilled and conscientious installers yielded a much better product. If abrasion is a concern, then the aggregate source for the concrete mix design should be harder than the streambed load. Extremely abrasive conditions, such as steep and rocky conditions, may require that the invert be steel plated. This is only necessary in areas that have shown resistance to concrete paving the invert.

Resources:

Reinforcing and curing materials

Cleaning equipment

Concrete finishing equipment

Concrete

Man hours

Small construction equipment

Operation:

- Dewater the area
- Prepare the area to be paved. This includes removing all debris from pipe. Steel needs to be cleaned of rust, oil, paint etc. All loose, spalled or unsound concrete sections need to be removed by scarification, chipping, sandblasting, waterblasting or other methods.
- Install steel reinforcement. If the repair is to be structural, then reinforcing bars need to be installed. The bars and mesh should be designed using traditional methods and must be anchored to the existing structure.

- Moisten earth, concrete and masonry structures. This needs to be done to avoid water absorption from the concrete mix. Standing water should not be allowed.
- Apply the concrete. The mix will need to be tested, delivered to the jobsite, and transported to the pipe. Mix design should limit shrinking. Care must be taken to allow the concrete to have adequate cover both above and below the reinforcing.
- Cure the concrete. This can be done with a curing compound or keeping the area damp through sprinkling or wet mats. Caution is needed when placing the curing materials to not disrupt the reinforcing.
- Clean up the jobsite.

Another option for invert repair is coating. Coating the surface extends the life of the culvert. Frequently coatings only add 1-2 years to service life. It is important to get a good bond between the original material and coating. Section 8.3.2.1 Material Selections includes various options for coating pipes. The most common is bituminous coating or painting the interior of the pipe. These choices should be used in areas with acidic conditions and low velocities and non-abrasive bedload. The cost will not be returned if the velocity or bedload wears off the coating in a short time period. Ideally the velocities should be below 5 ft/sec (1.5 m/sec) and the bedload should be soft, predominately silts and soils. If the bedload is granular, particularly if it is angular this treatment should be avoided.

Other options of coatings are available for more abrasive conditions. For example, Raven has a sprayable epoxy coating called AquataPoxy A-6. Other manufactures have similar products that have been used to reline manholes. It provides a very smooth surface and is highly resistive to corrosive environments. It requires man entry, but can be used for any size or shape, as well as at connecting cross pipes.

8.3.1.2 Masonry Repointing

Masonry culverts are in place across the state. Many have been extended with concrete structures. The concrete structures are in good condition, but the masonry sections are beginning to deteriorate, especially the grout areas. If these areas can be repaired prior to movement of the masonry units themselves, the service life of the culvert can be greatly increased. Once backfill material can be seen piping through the joints the success rate decreases. If replacement stones are used they must be sound and not have any defects. Most frequently a nearly zero slump concrete mortar mix is used, but other types of grout material are also available. See section 8.3.1.4, Joint sealing, for other possible grouts.

Many of these masonry culverts may be considered historic and may require specific environmental coordination. In general, if the culvert is being repaired and not changed significantly it may not be difficult to clear environmentally. Nonetheless, masonry culverts, particularly arch style, should be coordinated well in advance with environmental professionals before work begins. Other possible options to consider for masonry structures are sliplining (see Section 8.3.2.2) and cured in place pipe (see Section 8.3.2.3).

Resources:

Hand and small machine tools

Grouting equipment and grout

Dewatering equipment (possible)

Operation:

- Depending on the location of joints to be repointed, the work area may need dewatered.
- Clean the surface with high-pressure water, sand blasting, or other method.
- Ram pack or pressure grout the voids, making sure not to fill in any designed weep holes. Care should be given to completely fill areas behind masonry units, but not apply so much pressure that the unit becomes loose or dislodges.
- Cure the grouting material and clean the masonry face.
- Clean up job site

8.3.1.3 Timber Bracing and Repair

Bracing of culvert barrels should only be done on a temporary basis. Bracing may cause other problems due to the support pieces creating a debris collection point. This will create additional stresses on the pipe as debris collects. The debris will block the inlet and create pressure forces on the bracing, which may cause the bracing to collapse and ultimately increase the risk of culvert failure. The exception is repairing rotten or damaged sections of timber structures.

Proper bracing may be used to maintain the structural integrity of a pipe while other improvements can be engineered. When bracing is going to be used for any extended period of time, care should be given to deter debris from building up around the supports. More frequent inspections should be implemented, especially after peak runoff to check for and remove any debris.

Figure 8.5: Timber Bracing that Allowed Debris Collection

Resources:

Timber-generally pressure treated SYP (Southern Yellow Pine)

Galvanized Hardware

Man hours

Small construction equipment

Operation:

General:

When adding timber bracing, make sure to span the critical points and provide lateral support for weak areas. Do not put point loads on weak or critical areas. Look for areas that may be 'next' to take on the stresses and consider supporting these areas also.

For Rotted Area:

Replace the rotted area plus an additional two-foot along the grain. It is also suggested that a barrier be placed between the new segment and the old segment to reduce the chance of spreading rot and fungi. Barrier can be tarpaper, roof shingles, etc.

For Weak or Overloaded Areas:

Add a sister member and include a barrier layer. DO NOT install metal caps, as this provides a channel for water to filter directly onto the repaired area and increases the chance of additional rot damage.

8.3.1.4 Crack and Joint Sealing

Joints commonly become separated due to shifts in backfill. This can be caused during the original installation process or over time. Backfill is frequently more difficult to compact during part width construction, and this may lead to unstable backfill, and hence, separated joints. This can affect all types of pipe material. Uneven bedding, earthquakes, and frost heave can also cause joint separation. Separated joints are not a large concern if they have stabilized and backfill material is not 'seeping' into the pipe. 'Seeping' backfill can cause piping, which can lead to pipe failures if left unattended. Measurements should be taken over time to determine if the joints are moving or if they have stabilized. If backfill is infiltrating into the pipe, then the joint condition is more significant. There are several different types of fixes that can be used for sealing joints.

The most frequent maintenance treatment is grouting. Several types of grouting materials are available. The most common grout material is Portland cement based with or without admixtures. This allows some structural improvement, especially if fibers and reinforcing is included. It can fill voids completely and is the most economical grout material.

Chemical grouting with polyurethane foam can be used for non-structural joint repairs. It should not be used on longitudinal or circumferential cracks. It is applied in a foam, expands to fill the void, and stops infiltration. When it has cured it is hard but slightly flexible. It is suited well to wet joints and areas that are inlet controlled or below the water table. If the water is running from the joint the void can be filled first with grout soaked, oil-free oakum and then injected with grout. Care is needed so excessive pressure is not exerted on the pipe during the expansion process. This type of chemical grouting is generally used for minor voids caused by leaking or open joints. Installation should be according to the manufacture specifications.

Another chemical grouting material is urethane gel. It is less expensive than polyurethane foams, but is more difficult to install consistently since it reacts with any water in the surrounding soils. This leads to the necessity of having a knowledgeable contractor that can adjust the mixture on demand.

Epoxy grouts can also be used and provide some structural improvements. They are more frequently used for cracks and minor void problems. With all grouts it is important to follow the manufacturers installation instructions.

If there are significant structural problems other techniques should be included along with joint sealing such as sliplining or CIPP or adding repair sleeves.

Figure 8.6: Poor Joint Sealing that Allowed Infiltration

Resources:

Hand and small machine tools

Grouting equipment and grout

Dewatering equipment (possible)

Operation:

- Clean the area to be treated.

- Dewater the area if the grout material being used is not designed for use in wet areas. Failure to dewater the area when using concrete based grouts will cause the grouts to be weaker and not provide the strength or durability anticipated.
- Create an access point that allows for pressure grouting or a place for the grout to pond.
- May need to 'close off' the area to be filled with surface sealant to hold the grout in place when it is applied.
- Install grout material through pressure, gravity, or troweling.
- Allow for curing and clean the surface of repaired area.
- Clean up job site

Another frequently used option for sealing culvert joints is installing repair sleeves at the joint. This is a logical choice for separated joints that are not moving. It is also appropriate for pipes that have an isolated problem. If the problem is throughout the pipe other means of repair should be considered such as sliplining or CIPP. Installing sleeves or rings is often done in conjunction with grouting voids.

The original pipe material will impact the choice of rings. One major caution is that the area be clean to provide a watertight seal. On plastic pipes the deflection cannot be over 10%. There are several products that have been developed for specific types of culverts. The following list highlights some options.

Steel Bands

This product has been used in the roadway industry with success for many years. It involves installing a steel band and then shotcreting over it to protect against corrosion and abrasion. The bands have a gasket that seals off the area from further infiltration of the backfill. Any voids should still be filled before installing a steel band.

AMEX-10/WEKO-SEAL

This is a proprietary product that has been developed by Miller Pipeline. It is made from a rubber seal with stainless steel strips. It is available in a variety of different shapes ranging from 14" (0.35 m) to 108" (2.75 m). It can be used on precast and corrugated structures. This treatment is generally done using man entry to operate the hydraulic jacks, but can be done remotely.

Figure 8.7: AMEX-10/WEKO-SEAL Installation

(Ref. California DOT 2003)

LINK-PIPE (Stainless Steel)

This is another proprietary product that has been used in the sewer industry. It is suited for 12"-54" (0.30 m – 1.40 m) pipes and can be done remotely. The stainless steel liner sleeve is covered with a polyethylene foam gasket. It is coiled together and inserted into the pipe. When it is in place, the bands are cut and it is expanded until it snaps together with a slot type locking mechanism.

LINK-PIPE (PVC)

Another LINK-PIPE option for larger pipes is a PVC sleeve. It can handle pipe sizes from 36”-100” (0.90 mm-2.50 m). It involves man entry and the use of hydraulic jacks to expand the folded PVC pipe to the appropriate shape as depicted below.

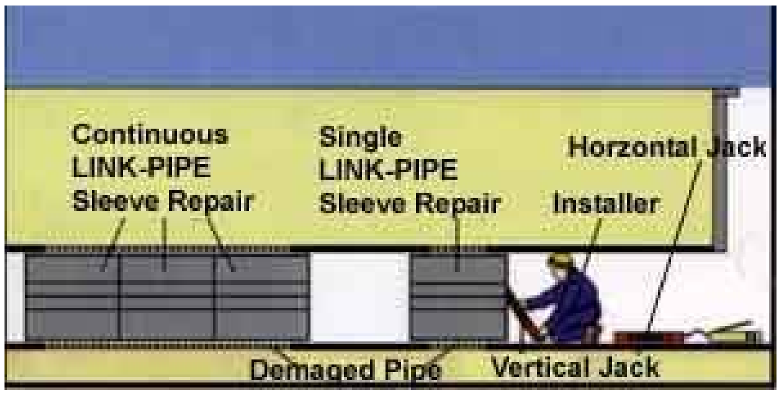


Figure 8.8: PVC LINK-PIPE Installation Process

(Ref. Report FHWA-IP-86-2)

This treatment should only be used for isolated problem locations. It can also be combined with several sections of LINK-PIPE to correct a larger problem area. One advantage is that it does not require dewatering, so it can be completed with little prep to the site during low flow conditions.

8.3.1.5 Concrete (Gunite) Lining

Concrete lining can be used to rehabilitate the inside of a pipe, seal headwalls, wingwalls, approach channels, and pave inverts. Concrete lining is often referred to as shotcrete or gunite. Shotcrete and gunite are basically the same process. Shotcrete refers to spraying on concrete with pneumatic hoses. Gunite is specifically spraying on a very dry mix of concrete with the water added at the hose through a ring that shoots the water through the mix as it is applied. Gunite is generally made with a sand aggregate mix; whereas, the wet mix can be made with larger aggregate. As with any concrete mix, additives and fibers can be included to increase the strength and durability of the mix. Generally, the mix design has a very low water cement ratio yielding a high strength concrete and minimum shrinkage. Concrete lining has the best success rate when placed over masonry, brick, steel and concrete. This type of treatment requires man entry, so pipe sizes are typically over 60 inches (1.50 m).

Concrete lining can be used to repair cracks and seal joints in masonry and concrete pipes. If there are voids behind the joints or cracks these must be addressed as part of the treatment. Following procedures listed in Section 8.3.1.4 can address this. Concrete lining can also be used over steel expansion bands to prevent corrosion.

There are some new processes that pull a machine through a pipe that has spinners attached to it that sprays concrete using centrifugal force. This is less than ideal since it does not allow for different thickness as needed, nor does it allow for structural repairs using rebars. A better option for pipes smaller than 60 inches (1.50 m) would be CIPP. Concrete lining on new pipes is available during the manufacturing process in a controlled environment and is good for corrugated steel pipes that will be used in acidic Ph environments.

Figure 8.9: Before and After View of Concrete Lined Pipe
(Ref. Insituform Technologies 2002)

Resources:

Reinforcing and curing materials

Cleaning equipment

Pneumatic shotcrete equipment

Shotcrete

Man hours

Small construction equipment

Operation:

- Dewater the area
- Prepare the area to be shot. This includes removing all debris from pipe. Steel needs to be cleaned of rust, oil, paint etc. All loose, spalled or unsound concrete sections need to be removed by scarification, chipping, sandblasting, waterblasting or other methods.
- Install steel reinforcement. If the repair is to be structural, then reinforcing bars need to be installed. The bars and mesh should be anchored.

- Moisten earth, concrete and masonry structures. This needs to be done to avoid water absorption from the concrete mix. Standing water should not be allowed.
- Apply the concrete. The mix will need to be tested, delivered to the jobsite, and pneumatically transported to the pipe. The operator should apply the mix using guidelines from the American Concrete Institute (ACI). Specifically, care should be taken to properly encase the reinforcing and to apply shotcrete with minimal rebound. Generally this requires that the shotcrete be applied at a 90-degree angle in a circular motion and filling corners first. Care needs to be taken around dowels to not create a 'sand pocket' behind the bars.
- Cure the concrete. This can be done with a curing compound or keeping the area damp through sprinkling or wet mats. Caution is needed when placing the curing materials to not disrupt the reinforcing.
- Clean up job site

8.3.2 Culvert Barrel Replacement Techniques

Culvert barrel replacement techniques are options that add structural integrity or completely replace the barrel of the culvert. This section is very diverse and includes techniques that have been used frequently for storm water systems and highway culverts. Some options, such as tunneling and boring, are expensive and will only be justified under specific conditions. Other options are very cost effective and should be considered frequently for structurally deficient culverts.

8.3.2.1 Material Selection

Material selection is a part of choosing the best replacement technique. Every material type has specific properties that will allow it to function in various environments. The following Table of Materials summarizes the sizes, specification references and capabilities for several culvert materials. In selecting the material type, key factors are abrasion and corrosive resistance. If the stream velocity is doubled, the abrasive power of the underlying bedload quadruples.

Table 8.2: Culvert Barrel Material Selection

Type A & B Conduits Only – Which are defined as Culverts or Storm sewers under pavement (Ohio Spec 603) in Ohio Specifications

Material Type	ODOT / ASTM Specification Reference	Typical Sizes Available	Strengths/Weaknesses
Corrugated Polyethylene (PE) Smooth Lined Pipe	707.33	4"-60"	Ribbed and corrugated sections are stronger than thin wall. Similar to HDPE properties. Must have well compacted backfill.
PVC (Polyvinyl Chloride)	707.41 707.42 707.43 707.44 707.45 707.46 707.47 ASTM A-789	Up to 48" circular,	Do not store in sunlight as this makes pipe brittle, must include headwalls to protect from sunlight. Brittle in temperatures below 3 degrees Celsius. Flammable. Must have well compacted backfill. Available in ribbed, corrugated interior, and smooth interior
HDPE (High Density Polyethylene)	SS 937 ASTM F-894 ASTM F-714	10"-120" (common up to 96")	Tough and flexible, handles freezing temperatures, good choice for slip lining, good abrasion resistance, likely to increase velocity. Smaller selection of qualified installers. Sections are heat fused together in the field. Relatively light therefore anchor to prevent floating during installation. Sunlight OK. Actual mix keeps changing and improving as manufactures perfect the product.

Material Type	ODOT / ASTM Specification Reference	Typical Sizes Available	Strengths/Weaknesses
Precast Reinforced Concrete	706.05 706.051 706.052 ASTM C-76	Available in boxes, 3-sided boxes and arches (up to 40' span), 4-sided (up to 20' span), circular (up to 144" dia.), and elliptical (up to 144" span).	Available in a wide range of sizes and shapes. Predictable construction methods, must have experienced operator to 'set' pipe in place. Shorter construction times than cast in place projects. Most common problems are joint defects and section drop off. In high sulfur content areas, such as mining areas, cement may disintegrate from the concrete, creating spalling and exposing the reinforcing. Best for ph ranges from 6-10. If pH is less than 5 then need to protect.
Corrugated Aluminum Alloy	707.21 707.22 707.23 707.24 707.25	Circular (6"-120") structural plate (60"-252"round and up to 30' arch, box), spiral rib	Not good in high PH areas that have fertilizer runoff, poor abrasion resistance, good resistance to mine water (low PH), sensitive to poor backfill, low cover. More flexible than steel. Available in wide range of sizes and shapes. Best for pH ranges between 4-9 and velocities less than 15 ft/sec (4.5 m/sec).
Reinforced Concrete Non-Reinforced Concrete	706.02 706.04 706.01 ASTM C-76	12"-144" circular elliptical	Available in a wide range of sizes and shapes. Predictable construction methods, must have experienced operator to 'set' pipe in place. Shorter construction times than cast in place projects. Most common problems are joint defects and section drop off. In high sulfur content areas, such as mining areas, cement may disintegrate from the concrete, creating spalling and exposing the reinforcing. Best for ph ranges from 6-10. If pH is less than 5 then need to protect.

Material Type	ODOT / ASTM Specification Reference	Typical Sizes Available	Strengths/Weaknesses
Bituminous Coated/Lined Polymerized asphalt	ASTM A-849 ASTM A-742 AASHTO M-190	1.25 mils minimum	Generally put on corrugated steel pipes. Can wear away in few years, faster in abrasive environments. Care needed during transport and installation to not damage coating. Poor for abrasion and sunlight conditions. Polymerized asphalt better in fish sensitive areas.
Epoxy Coated	706.03	Any size	Generally put on concrete pipes in aggressive chemical environments. Polyamide-cured, two component coal tar epoxy coating. Applied during manufacturing process, deters the breakdown of the cement in the concrete, not very effective in high velocity or abrasive bedload conditions.
Concrete/Mortar Coated (Lined)	707.11 ASTM A-849	24”-120”	Generally put on corrugated steel pipes in areas that need both corrosion and abrasion protection. Care must be taken to get good bond between the metal and concrete. Make sure bars are not exposed.
Aluminized Cladding	707.01 707.02 707.12		Coat steel to protect against corrosion. Works well for PH in the range of 5-9. Poor choice in abrasive prone areas. Acceptable for velocities below 15 ft/sec (4.5m/sec)
Metallic coated Corrugated Steel	707.01 707.02	Circular (6”-26’), elliptical (4’-21’), arches (various shapes up to 50’), boxes (up to 26’)	Most often coated with zinc alloy. Can be coated with other materials (See Coatings). ¼”-1” deep corrugations typical. Generally comes in galvanized steel that handles PH levels from 6-10 adequately. Areas where the galvanizing is damaged should be painted with a zinc rich paint as part of the repair. Most common problems are invert deterioration, and joint separation.

Material Type	ODOT / ASTM Specification Reference	Typical Sizes Available	Strengths/Weaknesses
Structural Plate Corrugated Steel	707.03	Generally circular or arch 5' to 26' span. Some boxes	Most typically used for low clearance, large waterway openings. Corrugations 2"-5" deep typical,
Vitrified Clay	706.08 ASTM C 700	Varies	Must specify Extra Strength only for culverts, resistant to abrasion and corrosion, weaker than other options, tendency to crack
Cast Iron		Varies	Generally not used in new installations, heavy, very brittle, cracks easily. If used must have good bedding. Very good against corrosion.
FRP (Fiberglass Reinforced Pipe)		8"-144"	Composite pipe, Mannings n = 0.009, carry structural loading, high resistance to extreme chemical environments
FRPC (Fiber Reinforced Polymer Concrete)		18"-96"	Expensive, common brand is HOBAS, strong, resistant to corrosion, long life

8.3.2.2 Sliplining

Sliplining is simply inserting a new pipe into the existing pipe and filling the annular space between the two pipes. This is one of the most versatile and beneficial options in culvert barrel replacement. When a pipe is properly sliplined with a new pipe, it functions close to a new installation, sometimes better. Sliplining can be used in many cases where the existing barrel has deteriorated. Its largest advantage is that the project can be completed with little to no impact on the traveled roadway. In addition, the cost is significantly less, especially if the culvert is under deep fill. If the host pipe has deformed in shape, a complete survey must be done to determine the possible sizes available for the new pipe. Frequently, a smaller smooth wall pipe will meet the hydraulic needs of the culvert. Care should be given to check the anticipated velocities from a smooth wall pipe as some form of velocity dissipaters, such as riprap may also be warranted. When lining the pipe, the corrosive and abrasive forces of the stream should also be evaluated. Culverts can also be extended during the lining process and thus roadways can be widened. There are several different styles of liner pipe that can be utilized. The materials section highlights different choices in pipe materials. The contractor can also be left with the option of selecting the pipe material, which may lead to the best price.

Resources:

Liner pipe

Grouting

Work crew

Specialized Equipment for the type of specific installation (selected by the contractor)

Operation:

- Dewater the work area
- Clean the host pipe
- Grout any voids behind the host pipe. This must be done to insure that the current void issues are addressed before the new pipe is inserted. Identify the locations, then drill and fill. Identification can be done by sounding and looking for evidence of areas that have infiltrated. Suspect areas can be further investigated. Care should be exercised to not overfill because of the pressure exerted by the grout.
- Choose appropriate new pipe material. This will determine when and how the pipe sections are connected. Some will be connected inside the host pipe, such as precast concrete sections. Corrugated metal sections are generally banded together outside the pipe. The pipe selection will be based on typical material applications and available workspace and equipment at the site. Selection should be based on the capability of inserting the pipe. Some joints cannot be pulled into place; other joints can be pulled and/or pushed. Corrugated pipes are generally more difficult to insert, especially into existing corrugated pipe.
- Place new pipe in host pipe. There are several different options for getting the new pipe into the host pipe. It can be pulled or pushed. This is an area that should not be specified in detail. Contractors may have built specialized equipment or discovered an innovative way that will work particularly well for

the site conditions. The low bidder may be the low bidder because he has come up with an ingenious way to insert the pipe into the host pipe. However, notes should be included that ensure the new pipe is put into place without causing harm to its shape, material, protective coatings, etc. Typically, it is specified to use guide rails, wood blocking, or other means as approved by the engineer.

- Cap off the ends to contain the grout, install grout tubes and possibly extra tubes to 'view' the grouting process.
- Grout between the host pipe and new pipe. Care must be taken to not float the new pipe in the host pipe. Grouting in lifts and/or providing spacers can accomplish this. The new pipe material must be stronger than the grouting pressure. Pipes can be fitted with ports on the top that will allow for inspection of grouting or pressure grouting relief valves. The most frequently used grout material is Portland cement based mortar or controlled low strength material (CLSM). Also, the grout, host pipe, and other fill behind the new pipe only needs to be as strong as well compacted soil for most applications.
- Clean up job site.

Within Ohio many culverts have been sliplined. One interesting location is under the ramp for State Route 668 on Interstate 70. This location was installed in the late 1980's and includes some interesting design features. Two different size liners were installed. A larger pipe was used at the inlet end to provide for better hydraulics that was necessary because of the overall reduction in pipe size. Inside the pipe, the size of the liner pipe was reduced because of shape distortions in the host pipe. After the liner was inserted and grouted into place the bottom was paved with concrete to increase the flow capacity and to combat corrosive factors against the steel liner. Today, this pipe is in very good condition as shown below.

Figure 8.10: Views of 15-Year-Old Sliplined Pipe (Licking County, Ohio)

8.3.2.3 Cured in Place Pipe (CIPP)

Cured in place pipe is a method that allows a new 'pipe within a pipe'. The pipe itself is made of a felt tube that is reinforced with fiberglass and coated with plastic. The felt tube is custom made for each specific site based on size, shape and structural integrity of the host pipe. The felt tube allows for the absorption of thermosetting resins. The pipe is wetted with resins during the manufacturing process or on site. Most often, they are applied at the manufacturing plant by a roller and then the pipe is shipped in a refrigerated truck to the project site for installation.

The CIPP is installed by inserting the pipe into the host pie through an inversion process. Most frequently, the pipe is inserted into place by water pressure. The pipe is sealed at one end and water is forced into the open end and 'turns the pipe right-side out' as it enters the host pipe. The resin impregnated tube should be snug against the walls of the host pipe with the plastic layer on the inside diameter. Once the CIPP is in place, the water is heated causing the thermosetting resin to harden forming a pipe within a pipe that requires no grouting.

Other options for inverting the pipe include using compressed air and heating the air into steam to set the thermosetting resins. In addition, some manufacturers offer CIPPs that can be winched into place and don't require the inversion process. If this option is chosen, extreme care must be taken to not contaminate the resins. If the resins are contaminated, the CIPP may not adhere well to the host pipe.

This process has been used frequently in the sewer industry and has provided municipalities' considerable savings. The two predominant manufacturers are Insituform and Inliner. Both provide design services and can custom design a liner to provide the size, shape, and strength requirements of a particular site. CIPP can also be used following tunnel operations to create the pipe walls after the tunneling procedures.

When evaluating if cured in place pipe is an appropriate option the following should be considered. The hydraulic capacity will generally increase, particularly with larger pipes, due to the smoothness of the polyurethane liner. Also, the size of the pipe will be decreased slightly, but far less than it would be if a slipliner and grout were specified. The CIPP requires that a frame be built to 'feed' the liner into place. This is generally done from the roadway surface, close to the end of the culvert. For this reason, there should be room on the shoulder or roadway to set up the haul truck, water heating equipment and inversion tubing. The impregnating of resin will be done off site for small or short sections, but will usually be done on site for larger or long runs. This is due to the weight and size of handling the larger liners.

CIPP installations can provide structural improvements, but the liner must be designed with the intent of structural support. Designers should be aware of the need to be able to insert the felt tube into the host pipe. If the host pipe has deteriorated to a point where the host pipe cannot be cleaned or made ready for installation, then CIPP is not a viable choice. In one case, a pipe was scheduled to be rehabilitated using CIPP and the pipe deteriorated to such a point that it was not safe to prepare the host pipe for insertion of the liner and a new treatment had to be selected.

A prime application for CIPP would be a metal culvert with a deteriorated invert and limited hydraulic capacity for the site. An ideal recommendation would be to fix the invert by filling voids and installing reinforcing and paving the bottom. Then install a custom designed CIPP. This would defend against the environmental conditions that caused the invert decay and maximize the hydraulic capacity of the pipe. If the pipe was bituminous coated, it may not be worthwhile to install the CIPP as the host pipe would need to be epoxy painted prior to CIPP installation. This is necessary to assure that the CIPP adheres to the host pipe and forms a bond to create a pipe within a pipe.

Environmentally the CIPP process presents pros and cons. The work area will be primarily from the road or shoulder surface. Minimal space is needed near the culvert entrance. This makes CIPP a good treatment for environmentally sensitive flora/fauna habitats. However, care must be used in disposing of the heated (150-200 degree) water used in the curing process. Another alternative is to use pressurized air to invert the pipe and then heat the air and allow the steam to cure the pipe. This also requires some care, as the air must then be allowed to cool and the condensation water trapped and disposed of properly. This will be a much smaller amount of water and provides flexibility in the use of this treatment.

Another advantage of CIPP is that the felt tube can be designed for various shapes, sizes and angles. This is particularly helpful for culverts that have been extended using different shapes and styles of materials. Furthermore, the CIPP can be designed with bends up to 90 degrees to allow for turns in the host pipe. Complicated shapes or angles will require a full survey of the dimensions so the felt tube can be custom designed to fit the host pipe and allow a smooth interior surface.

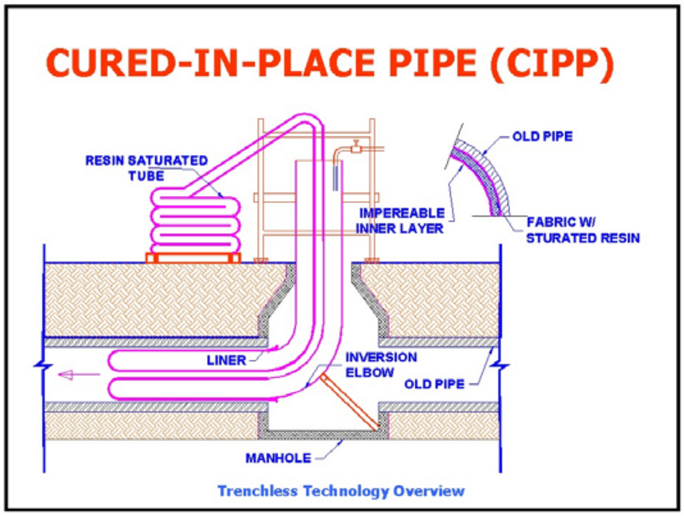


Figure 8.11: Cured-In-Place Pipe Installation
(Ref. Atalah 2003)

Resources:

Specially designed CIPP pipe

Work Zone traffic control

Work crew

Tower (scaffolding) for inversion tube

Water and heaters for inversion and curing process

Refrigerated storage or impregnation system on site

Operation:

- Dewater the work area
- Clean the host pipe
- Make any required structural repairs. Large voids should be filled and deteriorated inverts should be repaired. Small voids or scaling and rust do not need repaired unless shifts are evident in the structure. Remember any bituminous coating must

either be coated with epoxy paint or the CIPP liner must include a polyethylene preliner.

- Construct tower (scaffolding) to hold liner as it is forced into the pipe. The boiler and water supply must also be setup, along with the resin impregnation equipment if required.
- Install the liner. The CIPP liner is inside out upon delivery. If it has not been impregnated with resin this will be done as part of the installation process. One end of the line will be sealed. The liner is inserted into the host pipe and turned right side out by forcing water into the open end of the liner.
- Cure the liner. Once the liner is in place and forced against the sides of the host pipe the water is circulated through boilers and the heated water causes the thermosetting polyester and polyurethane resins to cure. Because heat is what cures the liner great care should be taken to keep the liner cool until it is in place and ready to be cured.
- Finishing. After the CIPP is in place and cured against the walls of the host pipe the water may be cooled and released slowly, if environmentally appropriate, or hauled away for cooling and disposal. The sealed end is cut open and any appurtenance work is performed.
- Clean up job site.

8.3.2.4 Pipe Jacking, Tunneling, Horizontal Directional Drilling

Pipe Jacking, horizontal earth boring and tunneling are all different methods of installing a new pipe via trenchless technology. This may be necessary to add hydraulic capacity to an area or to provide relief overflow during construction. It may also be used to install a new pipe to replace an existing pipe. It is not necessary to specify the specific type of trenchless technology to be used, only the type of pipe and limitations of work area. The contractor can make the selection of type of installation. The constraints of the site, and requested features, will narrow the options. The designer should be aware of the basic operation and limitations of different options.

Pipe Jacking

Pipe Jacking is most frequently done using reinforced concrete pipe, although any type of pipe that can handle the loads placed on it by the jacking equipment can be used. Pipe jacking is the most common form of trenchless technology used in highway culvert installation. The procedure is as shown below:

Pits are excavated on each side. The jack will bear against the back of the left pit so a steel or wooden abutment is added for reinforcement. A simple track is added to guide the concrete pipe sections. The jacks are positioned in place on supports.

A section of concrete pipe is lowered into the pit.

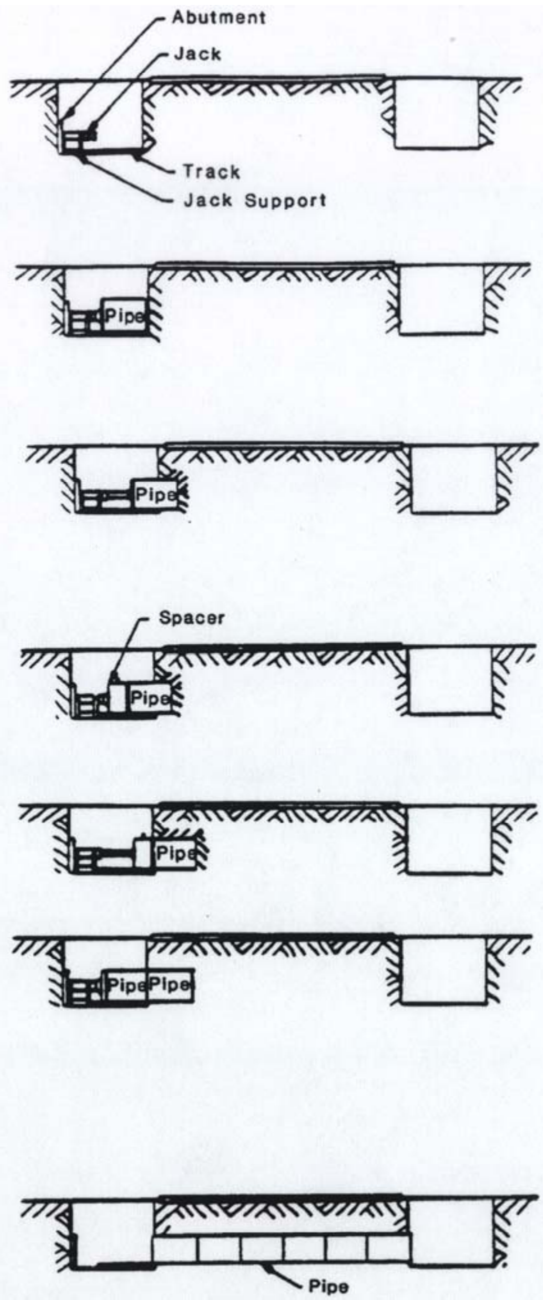
The jacks are operated pushing the pipe section forward.

The jack rams are retracted and a "spacer" is added between the jacks and pipe.

The jacks are operated and the pipe is pushed forward again.

It may be necessary to repeat the above steps four and five several times until the pipe pushed forward enough to allow room for the next section of pipe. it is extremely important, therefore, that the stroke of the jack be as long as possible to reduce the number of spacers required and thereby reduce the amount of time and cost. The ideal situation would be to have the jack stroke longer than the pipe to completely eliminate the need for spacers.

The next section of pipe is lowered into the pit and the above steps repeated. The entire process above is repeated until the operation is complete.



From FHWA-RD-95-089, Culvert Repair Practices Manual, Volume II, May 1995

Figure 8.12: Pipe Jacking Procedure

Tunneling

Tunneling is more expensive than pipe jacking and is most often used for large pipes, from 5'-26' (1.5 m – 8.0 m). It provides very accurate line and grade control. Any type of pipe may be installed into the tunnel after it is constructed. Tunneling is generally used for large-scale projects under deep fill or sensitive conditions. Detailed soil information is needed for tunneling contractors to bid a contract. The tunnel boring machine equipment includes five key components: wheel machine with specialized cutter heads, drum, excavator, and conveyor. The wheel machine rotates heads that are designed for the type of soils expected. The rotator head excavates the soils and they fall into the drum. Scoops inside the drum lift the spoils up to the conveyor. Outside the tunnel, haul equipment needs to be ready to dispose of the spoils. Boring machines can be operated from inside the tunneling machine or externally.

Figure 8.13: Tunnel Boring Machine Operation
(Ref. Insituform Technologies 2002)

Microtunneling

Microtunneling is basically a combination between tunneling and pipe jacking. It is for pipes in the range of 18"-54" (0.45 m – 1.40 m) and can accommodate a variety of types of pipe. It uses tunneling technologies on a smaller scale. The difference is that microtunneling installs the pipe during the tunneling process. The pipe can be any kind that can be connected to the tunneling equipment for insertion into the excavated region. Microtunneling is non-man entry. The set up for microtunneling equipment is expensive; so, it requires long runs to be cost efficient.

Figure 8.14: Micro Tunneling Operation
(Ref. Insituform Technologies 2002)

Horizontal Directional Drilling (HDD)

Horizontal Directional Drilling is a specific type of trenchless technology that involves installing a pilot hole then reaming the product pipe through the pilot hole. HDD is most often used with long runs of pipe and fused pipe sections. It provides very accurate line and grade. Excellent information needed to prepare a bid package is available from the Directional Crossing Contractors Association (www.dcca.org).

8.3.2.5 Pipe Bursting

Pipe bursting replaces structurally deteriorated pipe with a new pipe in the same location. It is most effective on unreinforced concrete, clay pipe and weak plastics. Pipe bursting can be used in areas that need to be replaced by a larger diameter pipe. The existing pipe is expanded into the surrounding soil and a new pipe is pulled into place. There are different machines designed to expand the existing pipe. The designer does not need to indicate the specific machine; only what size and type new pipe is required. Solid wall, fused HDPE is the most commonly used new pipe.

Pipe bursting has limited uses. It is only a viable option for pipes under 36" (0.91 m) and constructed of weak material. It is generally only recommended for clay and unreinforced concrete pipes in poor condition. It may be a valid choice for weak plastic pipes, but since plastic pipes are relatively new this requires more research in controlled conditions. Thoroughly inspecting the pipe prior to pipe bursting operations is vital. If the pipe encountered is too strong at some point along the pipeline this repair could become disastrous, as the first portion of the pipe has already been burst. Careful inspection via remote video or man entry is crucial to avoid this problem.

Figure 8.15: Pipe Bursting Operation

(Ref. Insituform Technologies 2002)

Operation:

- Prepare insertion and exit shaft pits. In highway culverts this should be relatively simple in most cases as the ends are generally exposed.
- Insert the expanding head, which is powered by either a pneumatic hammer or hydraulic expansion.
- Pull the bursting head through the existing pipe with the new pipe connected behind it.
- Add sections of pipe as the expanding head proceeds through the host pipe.
- Make any repairs or additions to the appurtenance structures
- Clean up the job site

8.3.2.6 Other Specialized Treatments

Fold and Form Lining

Fold and form lining is a variation of CIPP and sliplining. It involves deforming HDPE or PVC pipe so it will fit into the host pipe. After it is in the host pipe it is reformed to its original shape by introducing heated water or steam. Some pipes are grouted in the annular space while most form to the walls of the host pipe. Pipes can be expanded up to 110% of original designed diameter. Some manufacturers deform pipe on site, while others deliver pipe in a deformed state.

Figure 8.16: Fold and Form Lining Installation (Ref. Atalah 2003)

<u>Structural Panels from Insituform</u>

Insituform has developed structural panels for any size or shape that can accommodate man entry. The panels are constructed in one-third or one-half sections of pipe then fitted together inside the pipe. Then the annular space is grouted between the host pipe and connected panels. This treatment works well for pipes that change size, direction, or shape. It requires man entry to assemble the panels and install the grout. In essence it is a specialized sliplining process, and as such it is very expensive.

Figure 8.17: Renewal of 9-foot Sewer with Insituform Structural Panels

(Ref. Insituform Technologies 2002)

PVC Pipe Lining – Machine Wound PVC

This spiral wound process has been used by CALTRANS and is defined in ASTM F 1741. The following information is from Design Information Bulletin No. 83, CALTRANS Supplement to FHWA Culvert Repair Practices Manual, June 2003.

This method involves the insertion of a machine made field fabricated spiral wound PVC liner pipe into an existing pipe (either flexible or rigid). After insertion, the spiral wound PVC liner pipe is either:

a) Inserted at a fixed diameter and then expanded until it presses against the interior surface of the existing pipe; or,
b) Inserted at a fixed diameter into the existing pipe and is not expanded, and the annular space between the spiral wound PVC liner pipe is grouted; or,
c) Wound against the host pipe walls by a machine that travels down the pipe.

The expanding system consists of a continuous plastic strip that is spirally wound into the existing deteriorated host pipe. The male and female edges of the strip are securely locked together via the winding machine. Once a section is installed, it is expanded against the wall of the host pipe, creating a watertight seal. Both flexible and rigid pipes can be rehabilitated with this system. This lining system is similar to the fixed diameter process except that the continuous spiral joint utilizes a water activated polyurethane adhesive for sealing, no annular space grouting is required, but the pipe ends are usually grouted.

Figure 8.18: Machine Wound PVC installation

(Ref. California DOT 2003)

The fixed diameter machine spiral wound liner process produces a renovated pipe, which is a layered composite of PVC Liner (using ribbed PVC strips 200 to 300 mm wide that are supplied in 100 meter coils), cementitous grout, and the original pipe. The combination of the ribbed profile on the PVC liner and the grout produces an integrated structure with the PVC liner "tied" to the original pipe through the grout similar to a slipliner. Unlike the expanding system, after insertion, the annular space between the liner and the existing pipe is filled with grout.

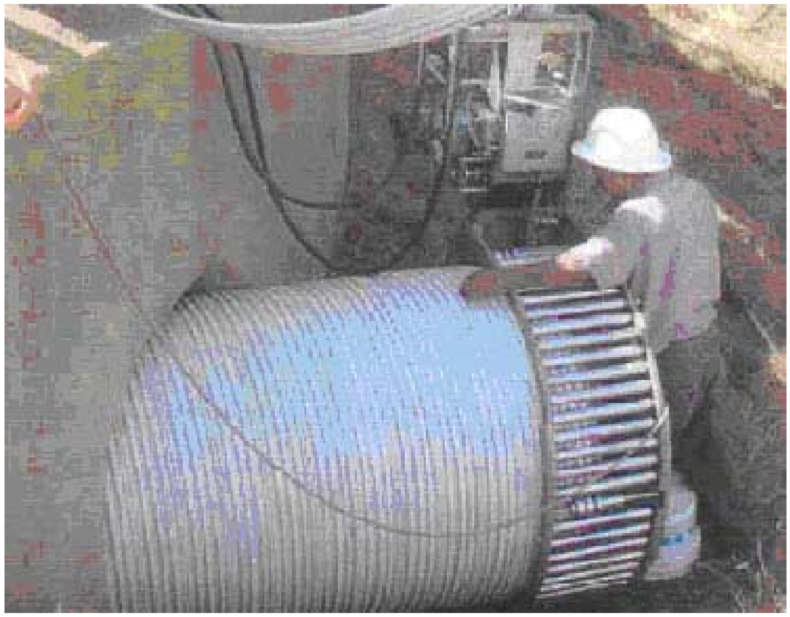


Figure 8.19: Rib Loc Ribsteel^{TM} Lining System Installation

(Ref. California DOT 2003)

The full bore, traveling machine system consists of a continuous plastic strip that is spirally wound into the existing deteriorated host pipe, with the option of a steel reinforcing section for increased load carrying capacity, by a machine that rotates and lays the profile against the host pipe walls as the machine traverses the host pipe. The male and female edges of the strip are securely locked together via the winding machine. The plastic strip is designed with ribs on its outer surface to engage a continuous strip of profiled reinforcing steel, which is added to the outside of the plastic pipe when specified. For many smaller applications the steel reinforcing is not required as the plastic strip has sufficient stiffness to withstand the grouting pressure. The resulting liner has a smooth plastic internal surface with increased stiffness from the steel reinforcing profile (if specified).

Figure 8.20: Full Bore, Traveling Machine System: Rib Loc Rotaloc^{TM} Lining System (Ref. California DOT 2003)

8.3.3.7 Open-Cut Replacement

Open cut replacement of deteriorated culverts has long been the standard in the highway construction business. This is still a viable option in some situations. It may be the most cost effect on low volume roads where the fill is minimal. Depending on the site, part width replacement may be an option by utilizing existing pavement or constructing temporary pavement. Special attention to compaction requirements is required at the part width joint to minimize future settlement problems. Open cut replacement should be discouraged for high volume, deep fill locations. Some advantages exist with open trench construction, such as the ability to include realignment or other roadway improvements. There are many choices of materials and a wide selection of contractors with experienced crews.

CHAPTER 9: SUMMARY AND CONCLUSIONS

9.1 SUMMARY

After performing an extensive literature review related to culvert inspection and risk assessment, a national survey was conducted to gain insights into state/district DOTs' culvert inspection policies and procedures. A set of eighteen survey questions were finalized between ORITE and Ohio Department of Transportation (ODOT) and sent electronically via the ODOT e-mail listing to DOTs. Two electronic mailings plus telephone follow-up were used to maximize the return. The questionnaire responses were analyzed carefully to point out national trends and innovative or creative solutions (if any) developed by some highway agencies.

Periodic inspection of culverts is an essential element for identifying the need for culvert maintenance, repair, or rehabilitation. Field inspection of a culvert structure can be a major task, since it involves systematic evaluations of the culvert material conditions, culvert shape and alignments, scouring at culvert ends, conditions of headwalls/wingwalls, roadway settlement, and embankment slope conditions. To develop an effective culvert field inspection program for the Ohio Department of Transportation, a comprehensive research project focused on culvert inspection and risk assessment methods was conducted by a team consisting of ORITE (Ohio University) and a sub-contractor (Jobes Henderson and Associates, Inc.).

An inventory list was requested from each ODOT district office for culverts that were recommended for the field inspection phase of this research. The selection criteria were left up to each ODOT district office. Sixty culverts (25 concrete, 25 metal, 10 thermoplastic) were selected from the inventory lists based on the diversity of the culvert type, geographical location, age, size, material type, shape, ADT, and water pH.

Before visiting each site, culvert background information were reviewed. This included general inventory data, maintenance records, and past inspection records. Then, field inspection work began by verifying the general inventory data (location, material, shape, coating, height of cover). The conditions of the culvert, roadway surface, headwall, channel, and embankment were noted, rated, and photographed. Both the ODOT and proposed rating systems were used in the field inspection. Two inspection data sheets were filed during/after the field inspection work. The field inspection phase produced a minimum sufficient amount of data for performing multi-variable statistical analysis and developing a risk assessment methodology.

Statistical analysis was performed using the collected data to identify key parameters that have a significant influence on the general rating of highway culverts in Ohio. The analysis was performed using the data collected according to both the ODOT and proposed rating systems to verify the overall effectiveness of the ODOT culvert rating methods. Statistical approaches used in the analysis included linear and nonlinear multi-variable regression models and tests of significance. The ODOT equations were applied to the collected data to estimate the culvert material durability. A methodology was proposed for evaluating culvert risk assessment, which was developed based on calculating the adjusted overall rating (AOR) of each culvert for both the ODOT and proposed rating systems. Maintenance immediacy and inspection course of action proposed by NCHRP 251 (1982) was correlated to each adjusted overall rating.

As developed by Jobes Henderson and Associates Inc., Chapter 8 described the current state-of-the-art and state-of-practice for culvert rehabilitation, upgrade, and replacement, using information gathered from a wide range of sources (professional journals, conference proceedings, manufacturer handbooks, and reports issued by FHWA and state DOTs, …). The topics covered in the chapter included invert treatment/replacement, masonry repointing, timber bracing, joint sealing, barrel reshaping, concrete lining, slip-lining, pipe jacking, pipe bursting, horizontal earth boring, tunneling, and open-cut replacement. A table was included to present guidelines for selecting proper culvert rehabilitation and replacement methods.

9.2 CONCLUSIONS

An extensive list of conclusions was reached during this study because of its multi-phased nature. Therefore, the conclusions are presented below according to the project objectives and tasks.

9.2.1 National Survey

One of the major tasks in this project was to conduct a national survey on highway culvert management policies and inspection/rating procedures. Forty responses were received, thirty-seven of which were from state DOTs. The following conclusions were obtained from the national survey:

- Forty-eight percent (48%) of the respondents were either bridge or hydraulic department personnel. Seventy-five percent (75%) of the respondents had prior experience in inspecting highway culvert structures. A variety of personnel are performing culvert inspection; including highway workers, engineers, and consultants.
- Forty-four percent (44%) of all respondents and forty-six percent (46%) of the responding state/district DOTs addressed confined space issues with regard to culverts.
- Sixty percent (60%) of the responding state/district DOTs have developed culvert inspection polices, and fifty-five percent (55%) of these specify the frequency of culvert inspection. Forty-eight percent (48%) of the respondents specified a one to two year cycle for culvert inspection, while sixteen percent (16%) specified a three to five year cycle. It should be noted that 60-70% of the respondent state DOTs borrowed the AASHTO definition (span ≤ 20 ft or 6.1 m) for the culvert.
- More than half of the responding state DOTs have applied numerical rating systems to evaluate in-service conditions of highway culverts. Among them, only five (equivalent to 13%) state/district DOTs other than Ohio have developed their own culvert inspection manual. Twenty-eight percent (28%) of the responding state DOTs apply the culvert numerical rating system developed by FHWA. Only one state other than Ohio (Texas) has developed a numerical rating system to

visually evaluate thermoplastic pipe culverts. Only five state DOTs have developed their own culvert risk assessment procedure.

- Fifty-seven percent (57%) of the responding state/district DOTs have a computer database to manage culverts.
- Most state/district DOTs based their decision to remove existing culverts on structural material deterioration, road surface conditions, and culvert shape (deflections). Culvert age and numerical rating scores are less cited in culvert replacement decision process.

9.2.2 New Culvert Management Policies/Procedures

Ohio Department of Transportation (ODOT) recently established new highway culvert management policies, inspection procedures, and rating methods. According to the new guidelines, any culvert having a span or diameter between 1 and 10 ft (0.3 and 3.1 m) should be inspected at least once every 5 years. ODOT developed two forms (CR-86, CR-87) to standardize the culvert data collection and data management in Ohio. The first form (CR-86) is an inventory data sheet, consisting of basic information such as culvert location, type, size, past modifications as well as hydrology/hydraulics data. The second form (CR-87) is a one-page culvert inspection document that requires 1 to 9 rating scores to be entered for reporting the conditions of the culvert, channel, and approaches.

9.2.3 Culvert Field Inspections

In the field inspection phase of this project, a total of sixty (25 metal, 25 concrete, and 10 thermoplastic pipe) highway culverts were inspected in a comprehensive manner using the ODOT as well as the proposed culvert rating systems. These sixty structures selected in the project represented a wide variation in terms of their geographical locations, environmental conditions, age, ADT, and height of soil cover. The following summarizes some of the conclusions regarding filed inspections:

- Environmental data collected at these sites were largely consistent with the state pH and flow abrasiveness maps produced by the ODOT Culvert Durability Study (ODOT, 1982).
- Conditions of the culvert structure, concrete headwalls, embankment slopes, and roadway surface rated and documented at the sites provided an overall picture of how each major type of culverts performs over time under major highways in Ohio.
- None of the concrete culverts had exhibited serious alignment problems. Also, the roadway surface over the concrete culverts showed no settlement problems. Based on this study, the service life of concrete culverts in Ohio appeared to be limited to 70 to 80 years.
- A total of nineteen (19) different characteristic conditions existed among the 25 concrete culvert sites. The most frequently encountered conditions were deteriorated headwalls, deterioration of concrete in the crown region/top slab and inlet end, and transverse shear cracks on abutment walls. In contrast, the least common conditions included cavity formation in adjacent soil fill, longitudinal crack(s), and embankment slope stability problem.

- Overall ODOT rating scores were very similar between the cast-in-place concrete box culverts and reinforced concrete circular/elliptical pipe (RCP) culverts.
- No serious culvert alignment problems were found at most metal culvert sites. No stress cracks were detected at the bolt lines inside any of the metal culverts. Based on the results of this study, the service life of metal culverts in Ohio appears to be limited to 60 to 65 years.
- A total of twenty-eight (28) different characteristic conditions existed among the twenty-five metal culvert sites. The most frequently encountered conditions were perforated invert, perforations at flow line, scour hole at inlet or outlet end, and movement on the concrete headwalls. The main location of perforation was in the invert for District 10 culverts and at the normal flow line for culverts outside District 10. In contrast, the least common conditions included severe rusting of plate edges and bolts at seams, pinholes in the top arc, reversal of curvature, and piping holes above the culvert.
- For metal culverts, the average ODOT rating score was the lowest on the general material condition. The second lowest average ODOT rating score was associated with the culvert shape. According to the proposed rating system applications, material deterioration was more of a concern for the invert region than for the other regions.
- The proposed rating scores established for the inlet and outlet end sections showed that at most metal culvert sites the inlet end section was no worse than the outlet end section.

- A total of twelve (12) different characteristic conditions were detected at ten thermoplastic pipe culvert sites. The most frequently encountered conditions were deflections larger than 7.5%, localized buckling of internal liner, and minor misalignment at joints. In contrast, the least common conditions recorded at the sites were separation of hydraulic liner, scour holes at inlet or outlet, and embankment slope instability.
- Due to a lack of field inspection data, no statement can be made concerning the service life of thermoplastic pipe culverts in Ohio.
- Inspection data indicated that the flexible (metal, thermoplastic pipe) culverts were sensitive to the installation conditions. Special attention is required during flexible culvert construction to make sure that it is installed according to specifications.
- The case of NOB-145-3.59 showed that a thermoplastic pipe can perform satisfactory for at least 20 years under severe (low pH, abrasive flow, shallow cover) service conditions.
- Results from application of the proposed rating system showed that the springline is the region where the first sign of structural distresses usually develops inside thermoplastic pipe culverts.

9.2.4 Statistical Analysis, Assessment of ODOT Durability Equations, and Risk Assessment Method

This section presents conclusions and discussions of the statistical analysis, assessment of ODOT durability equations, and risk assessment of the inspected culverts.

9.2.4.1 Statistical Analysis of Data Collected for Metal Culverts

The effects of the various independent variables listed in Table 7.1 were analyzed with respect to their effect on metal ratings (GA = general rating for ODOT rating systems and OMR = overall metal rating for the proposed rating systems).

- Age, rise, and culvert type were determined to be significant variables based on both rating systems.
- Water pH, abrasiveness, and flow velocity were also significant variables based on the proposed rating system.
- The linear regression model based on the ODOT rating system yielded the original and adjusted R^2 value of 0.5 and 0.43, respectively. The linear regression model based on the proposed rating system had the original and adjusted R^2 value of 0.81 and 0.75, respectively.
- The analysis overall showed that the proposed rating system detected more significant variables and had a higher value of R^2. This supports the fact that the proposed rating system had a higher resolution.

9.2.4.2 Statistical Analysis of Data Collected for Concrete Culverts

Field data collected at concrete culvert sites were analyzed to determine the significant variables that affect the durability of concrete culverts exposed to various in-service conditions. Several independent variables (listed in Table 7.6) were analyzed with respect to their effect on concrete ratings (GA = general rating for ODOT and OCSR = overall concrete surface rating for the proposed rating systems).

- Age and pH were significant variables based on both rating systems.
- Abrasiveness (of drainage flow) was also a significant variable based on the ODOT rating system.
- Analysis showed that the linear regression model based on the ODOT rating system detected more significant variables and had a higher R^2 value, even though the proposed rating system had higher resolutions and had more details for culvert inspection. Based on the low R^2 values resulted from both methods, additional data collection would be warranted.
- The statistical analysis was based on a small sample size (25 concrete culverts). Analysis of a larger sample size would reveal more details and increase the level of accuracy.

9.2.4.3 Statistical Analysis of Data Collected for Thermoplastic Pipe Culverts

Very limited statistical analysis could be performed on the thermoplastic pipe culverts, since only ten pipes were inspected and the average age was only about five years.

9.2.4.4 Assessment of ODOT Durability Equations

In the current study, the metal culvert durability equations, developed during the ODOT Culvert Durability Study (ODOT, 1982), were re-evaluated using the inspection data collected at twenty-five metal culvert sites in Ohio. Prior to the analysis, each original metal rating score obtained in the 0-to-9 scale had to be converted to an equivalent score in the 1-to-4 scale.

- The ODOT durability equations predicted the metal ratings relatively closely to the values assessed in the field under both the ODOT and proposed rating systems. In one isolated case (Metal Culvert No. 17), the ODOT metal culvert durability equations yielded a metal rating that was out of line with the actual metal conditions observed at the site. This was mainly due to uncertainty associated with its overall age, for the sections of this culvert structure was repaired subsequent to the original construction.
- Overall, results of the re-evaluation effort indicated that the current ODOT durability evaluation procedure for metal culverts appears to be reasonably accurate.

9.2.4.5 Risk Assessment of Inspected Culverts

Chapter 7 proposed a simple yet comprehensive methodology for evaluating risk assessment for each major culvert type. This methodology was developed based on the field inspection data and statistical analysis results obtained under both the ODOT and proposed culvert rating systems. The method adjusts the original overall culvert rating score by applying rating modifiers due to the culvert age, pH of drainage water, abrasiveness of drainage flow, and the height of soil cover to culvert rise ratio. And, the maintenance immediacy action plan developed by NCHRP Report No. 251 (1982) was adopted to relate the adjusted overall culvert rating (AOR) score to the recommended course of action.

- The AOR scores for the metal culverts based on the ODOT rating system were between 2 and 6. Metal Culverts No.3 and 16 had the highest and high priority of maintenance immediacy actions, respectively. The rest of the metal culverts' AOR scores were between 4 and 6. Therefore, their maintenance immediacy actions were mostly between 4 (Priority - current season) and 6 (Add to Scheduled work by end of next season).
- Very similar results were obtained for the AOR scores for the metal culverts under the proposed rating system. This supports the previous conclusion that the ODOT rating system for metal culverts is basically sound but can be improved further by adapting the additional elements (such as separate rating of the culvert ends, rating of the protective coating, rating of the invert paving, rating of the footing, …) contained in the proposed rating system.
- The AOR scores for the concrete culverts under the ODOT rating system were between 2 and 6. Concrete Culvert No.12 had the highest priority maintenance immediacy actions. Concrete Culvert Nos. 11 and 15 both required high priority of maintenance immediacy actions. For the rest of the concrete culverts, the AOR scores were between 4 and 6. Thus, their maintenance immediacy actions were between 4 (priority - current season) and 6 (Add to scheduled work by end of next season).
- Very similar results were obtained for the AOR scores for the concrete culverts under the proposed rating system. This supports the previous conclusion that the ODOT rating system for concrete culverts is basically sound but can be improved

further by adapting additional elements (such as separate rating of the culvert ends, rating of the footing, …) contained in the proposed rating system.

- The AOR scores for the thermoplastic pipe culverts under the ODOT rating system were between 6 and 9. Their maintenance immediacy actions were therefore between 6 (add to scheduled work by end of next season) and 9 (no repairs needed).
- The AOR scores of the thermoplastic pipe culverts based on the proposed rating system was between 5 and 9. Thus, their maintenance immediacy actions were between 5 (Place in current schedule - current season- first reasonable opportunity) and 9 (no repairs needed).
- It was observed for some combinations of the culvert type and the rating system that the AOR score was equal to the lowest of the individual item rating scores for almost half of the field cases examined. This observation should not lead to abandonment of the proposed risk assessment method. The factors involved in the AOR calculation (such as age, water pH, flow abrasiveness, and cover height to rise ratio) are all very important and must be considered in prioritizing the culverts in the culvert management plan.

9.2.5 Culvert Rehabilitation Techniques

The key to determining the best rehabilitation techniques is to arm the program manager and designer with a toolbox options. This requires that the existing structure be analyzed for deficiencies and that the cause of the current problems be determined. The cause must be addressed in selecting the appropriate treatment.

- Overall the best option will be the one that is appropriate structurally, hydraulically, environmentally, and fiscally. Several options have been presented in Chapter 8, with the following providing the most promise for use on a regular basis:

  Slip-Lining --- Section 8.3.2.2, Appendix G

  Cured-In-Place Pipe (CIPP) ---------------------- Section 8.3.2.3, Appendix G

  Invert Replacement Using Concrete or Gunite

  --------------- Sections 8.3.1.1 & 8.3.1.6, Appendix G

  Filling Voids -------------------------------------- Section 8.3.1.4

  Repair Sleeves for Localized Problems --------- Section 8.3.1.4

- If slip-lining options decrease the hydraulic capacity too much or if the host culvert changes direction and does not allow the installation of a liner pipe, then CIPP should be considered as an alternative. CIPP is a good choice if water is readily available with heating options and disposal of heated water. The water will most likely need to be disposed of into a water treatment facility. Steam may be used as an alternative, but the heated steam also needs to be cooled and released with care. If CIPP is used to repair structural deficiencies, the pipe material must be designed to provide structural support.
- Invert problems are common in Ohio, particularly in low pH areas. Invert replacement has been used successfully and is very cost effective if the installation is done in a quality manner.

- Filling voids can be a stand-alone treatment or included with sliplining, CIPP, and invert paving operations. It is important to fill voids before other treatments are undertaken to assure interaction between new barrels and the host pipe.
- Repair sleeves come in a variety of sizes, shapes and materials. Using repair sleeves is a form of preventative maintenance and can save money by repairing minor joint problems before more costly treatments are necessary. Manufacturers could train ODOT in-house staff on installation procedures as part of their Highway Technician Training Program.
- Table 9.1 summarizes the treatments discussed in Chapter 8. Rough cost information is also included to compare alternatives. There are other treatments available, but the ones illustrated here are the most promising for highway culvert barrel maintenance, rehabilitation, and replacement.

Many states recognize the need for a culvert inspection and renovation program, but few have made a full commitment to addressing the issue. California, Ohio and Indiana are leading the way. They have tried a variety of techniques and are looking toward the future for more innovative options. Indiana has allocated funds specifically to culvert replacement and repair. Without a financial commitment the needs may go unaddressed. Everyone involved in the program process needs to recognize the safety implications and value of using innovative repair and replacement techniques wisely.

Table 9.1: Different Culvert Barrel Treatment Options

Type of Treatment	Cost	Size	Comments	Limitations
Invert Replacement 8.3.1.1	F-2 C-MED Ohio-$96/LF plus incidentals Maryland-$16.22/SF concrete, $21.80/SF gunite plus incidentals	Any size, any shape	• Must provide steel to increase structural value. • Allow for adequate coverage of steel mat. Any voids under the invert should be addressed prior to the invert paving. • Can add polymer or epoxy sealer similar to bridge deck coatings to enhance corrosion protection. • Various forms of coating materials are available for non-structural repairs.	• Most applications requires man entry. • Can be pumped in and finished using traditional methods or put in using shotcrete (see Concrete or Gunite lining). • Smaller sizes will be done using robotic equipment and are less likely to provide a good product
Masonry Repointing 8.3.1.2	F-1	Over 60" equivalent, Any shape	• Mortar can be installed by pressure grouting or packed into voids.	• Any replacement stones should be at least 6" deep with length and width ratios at least 1 ½ times depth. • Do not do work during freeze cycles.
Timber Bracing 8.3.1.3	F-2	Over 60" equivalent	• Allows for short-term fix to prevent collapse. • Need to check frequently for debris collection around bracing.	• Strictly temporary fix. • Make plans for more complete treatment
Timber Repair 8.3.1.3	F-1	Over 60" equivalent	• Used for repairing damaged or rotted sections of existing timber structures. • Excellent against corrosive runoff. Always use pressure treated lumber and galvanized hardware.	• Must be consistently under water and not go through drying cycles to maintain strength.

Type of Treatment	Cost	Size	Comments	Limitations
Sealing Joints and Voids 8.3.1.4	F-1 C-Low	Man entry, generally at least 36"	• Cracks or joints that are moving should be filled with a flexible material. • Cracks and joints that are stable should be filled with a rigid material. • Can use different types of bands for isolated problem areas. See Section 8.3.1.4 for details. Fill voids before adding bands.	• Must be sure that air or water is not trapped when filling voids and cracks. Very important to determine the extent of the voids. • Most common practice for installing grout materials is to place tubes at top and bottom of void and pressure grout into bottom until the grout comes out the top. • Voids under culverts may be filled by gravity but it is best to dewater the area first or the properties of the grout will change as the additional water is encountered leading to a poor grout mix.
Concrete Lining (Shotcrete or Gunite) 8.3.1.6	F-2 C-High	Over 60"	• Good for odd shaped pipes, best for fixing cracks and minor joint defects before voids have formed. Also good for headwalls, wingwalls, and paving inverts. • Can be a structural repair if reinforcing is included. Variety of mixes available with additives. Provides corrosion resistance for metal pipes. • Good choice for changes in direction or odd shapes. • Eliminates the need for form work. • Bonds well to concrete, masonry, rock, steel. • Can put in variable thickness as needed. • May increase flow capacity by reducing roughness on corrugated pipes.	• Requires man entry. • Looks like precast when done, need experienced 'nozzleman' for gunite since he is controlling the water being added. • May need significant footprint for setting up concrete pumping or mixing operation.

Type of Treatment	Cost	Size	Comments	Limitations
Sliplining 8.3.2.2	F-3 C-Med Ohio-$170/LF plus $160/CY grout plus incidentals	Anything large enough to clean well	• Provides structural repair, allows roadway widening if needed, very versatile. • Wide choice of materials available. Construction is invisible to the traveling public. Opportunity to change pipe material to combat environmental issues.	• May change hydraulic capacity.
CIPP (Cured in Place Pipe) 8.3.2.3	F-N/A C-High See Section 8.2.2	6"-72" + any shape, custom fitted	• Can provide some additional structural support with appropriately selected resins and fibers, doesn't decrease size significantly. • Can be designed for specific shapes and sizes. Good choice for smaller pipes that cannot be easily sliplined. • Can accommodate directional changes in host pipe. • Smooth lined usually increase hydraulic flow. • There are a few new products that are pulled into the host pipe then expanded with compressed air and the air is heat-ed to cure the liner. • Can accommodate lateral connections.	• Limited experience in Ohio in highway industry. • No need to grout annular space. • Provides jointless construction. • Product must be refrigerated before installation or impregnated at the site. • Need significant amount of water and ability to heat it and dispose of possible styrene-contaminated water to perform inversion and curing process. • Not a good choice for bituminous lined culverts because will require lining with plastic barrier or applying epoxy paint first so resin can cure properly.

Type of Treatment	Cost	Size	Comments	Limitations
TT (Trenchless Technology)-Pipe Jacking 8.3.2.4	See Section 8.2.2	36”-132”	• New pipe installed as a one step process for new location or adjacent to existing location.	• Pipe Jacking-man entry unless augers are used for material removal. • Best to be continuous process so pipe will not ‘set’ or ‘freeze’ in place. Longer lengths may require intermediate jacking pits, such as in median of interstates, good line and grade control from inside pipe. • Above groundwater table. • Safety concerns from high pressure lines and hydraulic jacks if not properly used. • Can not go through rock sections. • Best to have uniform soils.
TT (Trenchless Technology)-Tunneling and Microtunneling 8.3.2.4	See Section 8.2.2	12” to 26’	• Can install new pipe at new location or adjacent to existing pipe. • Capable of going under deep fills. • Very accurate line and grade. Wide range of sizes. • Can be below groundwater level. Frequently tunnel is constructed, then pipe is inserted in place. • Micro-tunneling is a one-phase operation with the pipe installed during the tunneling process.	• Expensive, few contractors in high-way industry. • Need good soils information.

Type of Treatment	Cost	Size	Comments	Limitations
Pipe Bursting 8.3.2.5	See Section 8.2.2	Max is 36”	• Replaces a pipe at same location with a larger diameter pipe. Provides a new pipe structure. • Can expand pipe up to 30%. Can add structural integrity. • No need for bypass pumping; can be done under normal or low flow conditions.	• Host pipe must be unreinforced concrete, clay or possibly weak plastic. • Can not use in expansive soils. • Can not fix line and grade problems.
Fold and Form Pipe 8.3.2.6	C-Med to High	Up to 24”, circular	• Similar uses as CIPP. • Smaller sizes, PVC (ASTM F 1504), HDPE. • No grouting needed. • Easy transport.	• PVC or HDPE pipe that is folded or deformed so it can be pulled into host pipe then reformed. • Specialized equipment. • Cannot handle joint settlement or diameter variations.
PVC Pipe Lining - Machine Wound PVC 8.3.2.6	C-High	6”-9’	• Relines a pipe with PVC. • ASTM F- 1741. • Various types of techniques, some require grouting. • Small footprint for work area.	• Limited suppliers. • Not in common usage. • No performance data. • Similar limitations as PVC sliplining. • Specialized equipment. Hard to handle diameter changes.
Open Cut Replacement 8.3.2.7	See Section 8.2.2	Any size, Any shape	• Total replacement of pipe; can add structural strength and capacity. • Any choice of material. Conventional style construction well tested. • Can include roadway alignment changes in project.	• Can be expensive, especially for deep fill. • High user costs caused by lane closures and detours.

<u>Cost Codes</u>

The above column labeled costs can be interpreted using the following key:
F = cost relative to replacement as indicated in FHWA-RD-95-089, Culvert Repair Practices Manual, Volume II, May 1995. Scale of 1 (Low) – 5 (High); **C** = cost as indicated in Design Information Bulletin No. 83, CALTRANS Supplement to FHWA Culvert Repair Practices Manual, June 2003. Scale of Low to High; and **Ohio** = Ohio’s costs based on bid tabs and Summary of Contracts Awarded.

9.2.6 Demonstration of CPT Sounding Technique

Results of the cone penetration test (CPT) investigations conducted at selected culvert sites are presented in Appendix H. During the current study, it was demonstrated at a few sites that the cone penetration test (CPT) can be a useful tool for evaluating the quality of backfill soil envelope around the culvert. The zone of weak (or loose) soil or voids near the culvert can be easily identified, without open excavation, through significant reductions in the tip resistance and sleeve friction readings. In most cases, the CPT sounding can be achieved relatively quickly by closing only one traffic lane. The only difficulty associated with the application of CPT is that prior to each testing the hole location must be precisely determined on the roadway surface, so that the CPT probe will penetrate within a few feet of the culvert.

CHAPTER 10: IMPLEMENTATIONS

Based on the findings made and conclusions reached in the current comprehensive study on highway culverts, the following general implementation plans are recommended by the authors:

- The drainage water pH contour map published by the ODOT Culvert Durability study (ODOT, 1982) can still be used for evaluating the normal pH of the drainage flow in Ohio.
- In 96% of the metal culverts inspected, the ODOT culvert durability formulas developed 20 years ago proved to be still reliable in estimating the metal culvert material durability. Therefore, the metal culvert durability equations, developed during the ODOT culvert durability study (ODOT, 1982) can be continually utilized to predict the service life of metal culverts. Prior to the use of the durability procedure, the metal rating score must be converted from the 0-to-9 scale value to an equivalent value based on the previous 1-to-4 scale. It is recommended that the formulas be verified further since the outcome for one metal culvert was not consistent.
- To better convey information to County and District personnel, the portions of this report (especially Chapter 8 and Appendix G) should be used as a basis for A Culvert Maintenance Manual or Supplement to the Maintenance Administration Manual.

- It is recommended that a specific Strategic Highway Research Program (SHRP) be developed on the national level to apply several culvert rehabilitation options in different environmental site conditions and track their progress during and after construction phases.

It is recommended that the following changes/additions be made to the new guidelines, policies, and methods presented in the ODOT Culvert Management Manual (2003):

- The metal culvert rating system developed by ODOT (2003) is basically sound. However, it will become more effective if each culvert end is rated independently from the main barrel, if the culvert material condition is evaluated in each region (top, sides, invert) separately, if the rating system for protective coating is added, if the rating system for invert pavement is added from the ODOT Culvert Inspection Manual (1990), if vertical deflection is used exclusively to evaluate the culvert shape, and if a clear instruction is given to rate the headwalls at inlet and outlet separately.
- The concrete culvert rating system developed by ODOT (2003) is basically sound. However, its effectives can be improved further if each culvert end is rated independently from the main barrel, if the culvert material condition is evaluated in each region (top, sides, invert) separately, and if a clear instruction is given to rate the headwalls at inlet and outlet separately.

- The thermoplastic pipe culvert rating system developed by ODOT (2003) is basically sound. However, it will become more complete if each culvert end is rated independently from the main barrel, if the culvert material condition is evaluated in each region (top, sides, invert) separately, if the degree of wall cracking is addressed, if the vertical deflection is used exclusively to evaluate the culvert shape, and if a clear instruction is given to rate the headwalls at inlet and outlet separately.

Finally, the following additional recommendations are made to ODOT to achieve an effective state-wide culvert management program and reduce the risk of structural collapse of short-span culverts serving major highways in Ohio:

- The culvert age, the cover height-to-rise ratio, and environmental conditions (abrasive nature and pH of the drainage flow) prevailing at the site should be factored into determining the frequency of field culvert inspection. Deteriorating culverts that are older and/or having a low cover height-to-rise ratio should be inspected more frequently.
- Once a set of culverts is identified as needing work in any ODOT districts, the AOR (adjusted overall rating) method presented in this report should be utilized to prioritize the work schedule among the list. The lower the AOR score is, the higher the priority for repairs/replacement. Then, based on the AOR score the realistic time line for remedial work should be developed.

- By the time this report was drafted, a few ODOT districts had each acquired a personnel who would be conducting filed inspection of highway culverts according to the new ODOT culvert rating systems. It is recommended that the proposed culvert risk assessment method be applied by these personnel during the data management phase. Also, as additional field inspection data are obtained, it is recommended that these data be incorporated into the statistical analysis.
- Installation of any culverts larger than 36 inches in diameter/rise at state highway project sites should be monitored and documented more closely monitored and by both contractors and state DOT personnel.
- During the initial backfilling of flexible (metal, thermoplastic pipe) culvert, the soil stiffness gauge (SSG) should be used, in stead of the conventional nuclear moisture/density gauge. This is because stiffness is a better indicator of the quality of soil fill than dry density. Guidelines for using the SSG in the flexible pipe installation work can be found in a technical paper by Sargand et al. (2004).
- The cone penetration test (CPT) should become an integral part of the overall investigation efforts at any culvert site where the culvert performance has been less than satisfactory and the cause of the poor performance is unknown.

BIBLIOGRAPHY

<u>List for Chapters 1 Through 7 & Appendix H</u>

AASHTO (1999). *Volume XIV: Highway Drainage Guidelines for Culvert Inspection and Rehabilitation*, Washington, D. C., 39 pp.

Abdel-Sayed, G., Bakht, B., and Jaeger, L. G. (1994). *Soil-Steel Bridges – Design & Construction*, First Edition, McGraw-Hill, Inc., New York, 357 pp.

Arnoult, J. D. (1986). *Culvert Inspection Manual*, FHWA-IP-86-2, Final Report, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 205 pp.

ASCE Civil Engineering Magazine (2002). Special Article Titled "Product Progress for the Pipeline Industry." American Society of Civil Engineers, pp. 82-93.

Cahoon, J. E., Baker, D., and Carson, J. (2002). "Factors for Rating Conditions of Culverts for Repair or Replacement Needs." Transportation Research Record (TRR), Journal of Transportation Research Board, Vol. 1814, National Research Council, Washington, D. C., pp. 197-202.

Cowherd, D. C., and Corda. (1994). "Lessons Learned from Culvert Failures and Nonfailures." Transportation Research Record (TRR), Journal of Transportation Research Board, Vol. 1431, National Research Council, Washington, D. C., pp. 13-21.

Degler, G. H., Cowherd, D. C., and Hurd, J. O. (1988). "An Analysis of Visual Field Inspection Data of 900 Pipe-Arch Structures." Transportation Research Record (TRR), Journal of Transportation Research Board, Vol. 1191, National Research Council, Washington, D. C., pp. 46-56.

Federal Highway Administration (FHWA). (1979). *Bridge Inspector's Training Manual*, U.S. Department of Transportation, Washington, D.C., 205 pp.

Hardipriono, F. C., Larew, R. E., and Lee, O. Y. (1988). "Service Life Assessment of Concrete Pipe Culverts." Journal of Transportation Engineering, American Society of Civil Engineers, Vol. 114, No. 2, pp. 209-221.

Hurd, J. O. (1986). "Field Performance of Corrugated Polyethylene Pipe Culverts in Ohio." Transportation Research Record (TRR), Journal of Transportation Research Board, Vol. 1087, National Research Council, Washington, D. C., pp. 1-6.

Hurd, J. O. (1986). "Field Performance of Protective Lining for Concrete and Corrugated Steel Pipe Culverts." Transportation Research Record (TRR), Journal of Transportation Research Board, Vol. 1001, National Research Council, Washington, D. C., pp. 40-45.

Hurd, J. O. (1988). "Service Life Model Verification for Concrete Pipe Culverts in Ohio." Transportation Research Record (TRR), Journal of Transportation Research Board, Vol. 1191, National Research Council, Washington, D. C., pp. 118-131.

Johnson, D., and Zollars, J. (1992). "Culvert Renewal." Minnesota Department of Transportation (Minn DOT), Office of Materials and Research, St. Paul, Minnesota.

Kurdziel. (1988). "Culvert Durability Rating Systems." Transportation Research Record (TRR), Journal of Transportation Research Board, Vol. 1191, National Research Council, Washington, D. C., pp. 132-140.

Kurt (1991). "Microcomputer-Based Culvert Ranking System." Transportation Research Record (TRR), Journal of Transportation Research Board, Vol. 1315, National Research Council, Washington, D. C., pp. 21-27.

McGrath, T. J., and Beaver, J. L. (2003). "Condition of Highway Culverts and Determination of Performance Measures." Draft Final Report to Utah Department of Transportation, Project No. 81FR0132, Salt Lake City, Utah.

Meacham, D. G., Hurd, J. O., and Shisler, W. W. (1982). *Ohio Culvert Durability Study*. ODOT/L & D/82-1, Ohio Department of Transportation (ODOT), Columbus, OH, 173 pp.

Missouri Department of Transportation (2001). *Culvert Study Report*, Report No. RDT00-004, 29 pp.

National Cooperative Highway Research Program (NCHRP) Report No. 50 (1978). *Durability of Drainage Pipe*, Transportation Research Board, National Research Council, Washington, D.C..

National Cooperative Highway Research Program (NCHRP) Report No. 251 (1982). *Assessment of Deficiencies & Preservation of Bridge Substructures Below the Waterline*, Transportation Research Board, National Research Council, Washington, D.C., 80 pp.

National Cooperative Highway Research Program (NCHRP) Synthesis No. 254 (1998). *Service Life of Drainage*, Transportation Research Board, National Research Council, Washington, D.C., 39 pp.

National Cooperative Highway Research Program (NCHRP) Report No. 438 (2000). *Trenchless Installation of Conduits Beneath Roadways,* Transportation Research Board, National Research Council, Washington, D.C., 76 pp.

National Cooperative Highway Research Program (NCHRP) Synthesis No. 303 (2002). *Assessment & Rehabilitation of Existing Culverts*, Transportation Research Board, National Research Council, Washington, D.C., 74 pp.

Ohio Department of Transportation (1982). *Ohio Culvert Durability Study*. ODOT/L & D/82-1, Columbus, OH, 173 pp.

Ohio Department of Transportation (1990). *Culvert Inspection Manual*, Columbus, OH, 30 pp.

Ohio Department of Transportation (2001). *Bridge Inspection Manual*, Columbus, OH, 78+ pp.

Ohio Department of Transportation (2003). *Culvert Management Manual*, Columbus, OH, 64+ pp.

Ohio Department of Transportation (2003). *Location & Design Manual*, Columbus, OH.

Ratliff, A. (2003). "An Overview of Current & Developing Technologies for Pipe Condition Assessment." Proceedings of ASCE Pipelines 2003 Conference, pp. 103-113.

Robertson, P. K. (1990). "Soil Classification Using the Cone Penetration Test." Canadian Geotechnical Journal, Vol. 27, pp. 151-158.

Sargand, S. M., Masada, T., Tarawneh, B., and Hanna, Y. (2004). "Use of Stiffness Gauge in Thermoplastic Pipe Installation." Journal of Transportation Engineering, ASCE, Vol. 130, No. 6, pp. 768-776.

Stein, D. (1990). "Recent Advances in Structural Rehabilitation Techniques for Underground Sewer Pipelines." Proceedings of ASCE Pipelines 1990 Conference, pp. 32-45.

Temple, W. H., and Cumbaa, S. L. (1986). "Evaluation of Metal Drainage Pipe Durability After Ten Years." Transportation Research Record (TRR), Journal of Transportation Research Board, Vol. 1087, National Research Council, Washington, D. C., pp. 7-14.

Walpole, R. E., and Myers, R. H. (1989). *Probability and Statistics for Engineers and Scientists*, 4th edition, MacMillan Publishing Co., 765 pp.

List for Chapter 8

Akkerman Products, Inc. (2004). <http://www.akkerman.com.>, Products Section, Brownsdale, Minnesota.

American Society of Civil Engineers, (2001). *Standard Construction Guidelines for Microtunneling*. Reston, Virginia, 41 pp.

American Society of Civil Engineers (2003). *Design Guidelines for Pipeline Renewal Systems, ASCE Manuals & Reports on Engineering Practice*. ASCE PINS Committee Task Force. Reston, Virginia, 57 pp.

Atalah, A. (2003). *Trenchless Technology Overview*. Bowling Green, Ohio. <http://mstt.com>.

Ballinger, C. and Drake, P. (1995). *Culvert Repair Practices Manual*, FHWA-RD-94-096, Volumes I and II, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 265 pp.

Barnhouse, J. P. (2003). D11-CR-FY2003, PID 19523 Contract Plans, Ohio Department of Transportation, District 11, New Philadelphia, Ohio, 20 pp.

Barnhouse, J. P. (2004). D11-CR-FY2004A, PID 21656 Contract Plans, Ohio Department of Transportation, District 11, New Philadelphia, Ohio, 28 pp.

Bauer, G. (2003). "City of Ottawa Uses Cured-In-Place Lining to Rehabilitate Sanitary Sewer Access Structure." Trenchless Technology, Volume 12, No. 6, Peninsula, Ohio, pp.37-38.

Cahoon, J. E., Baker, D., Carson, J. (2002). "Factors for Rating Condition of Culverts for Repair or Replacement Needs." Transportation Research Record (TRR), Journal of Transportation Research Board (TRB), Volume 1814, National Research Council, Washington, D.C., pp. 197-202.

California Department of Transportation: Division of Design, Office of State Highway Drainage Design (2003). "Design Information Bulletin No. 83; Caltrans Supplement to FHWA Culvert Repair Practices Manual." Sacramento, California, 109 pp.

Callaghan, J. L., (2004). Plan Sheet for Invert Paving to Structure No. 12186xo on US 1 Bus Over Tributary of Bynum Run, Maryland State Highway Administration.

City and County of Denver Department of Public Works, Engineering Division. (2004). "Storm Drainage and Sanitary Sewer Construction Detail and Technical

Specifications." Denver, Colorado, <http://www.denvergov.org/forms/dts10-7.pdf>, 11 pp.

Coker Pipe Rehab, Inc. (2003). "Giving New Life to Old Pipe." Specifications, Woodstock, Illinois. <http://www.cokerpipelinerehab.com>, 4 pp.

Davis, P. (2004). *Draft Specification for Machine Spiral Wound PVC (Expandable Liner) and Spiral Wound PVC (Fixed Diameter)*, CALTRANS, Office of State Highway Drainage Design.

Directional Crossing Contractors Association (1995). *Guidelines for a Successful Directional Crossing Bid Package*, Dallas, Texas, 11 pp.

Directional Crossing Contractors Association (1998). *Guidelines for Successful Mid-Sized Directional Drilling Projects*, Dallas, Texas, 10 pp.

Federal Highway Administration (1986), *Culvert Inspection Manual*, Report No. FHWA-IP-86-2. Supplement to the Bridge Inspector's Training Manual*,* Washington, D.C.

Gangavarpu, B. (2003). "Missouri Department of Transportation Favors Pipe Jacking." Trenchless Technology, Volume 12, No. 4, Peninsula, Ohio, pp. 29-30.

Indiana Department of Transportation (2003). CURED-IN-PLACE PIPE LINERS, Supplemental Specifications, Indianapolis, Indiana, 3 pp.

Indiana Department of Transportation (1999). SECTION 715 – PIPE CULVERTS, STORM AND SANITARY SEWERS, Specifications. Indianapolis, Indiana, pp. 522-535.

Indiana Department of Transportation (1999). SECTION 716 – TRENCHLESS PIPE INSTALLATION, Specifications. Indianapolis, Indiana, pp. 535-539.

Indiana Department of Transportation (1999). SECTION 725 – SLIP LINING OF EXISTING PIPE, Specifications. Indianapolis, Indiana, pp. 580-586.

Infrastructure Technologies (2004). "General Specifications and Guidelines for Installation of the Masterliner Cured-In-Place Pipe Systems." Rogers, Minnesota. <http://infratech.info/master-liner-spec.htm>, 14 pp.

Inliner Technologies (2004). Engineering Design Guide, Inliner Technologies, Paouli, Indiana, 41 pp.

Insituform Technologies, Inc. (2002). <http://www.foldandform.com>, Products and Services Section, Resource Room Section, Chesterfield, Missouri.

Iseley, T. and Gokhale, S. B. (1997) “Trenchless Installation of Conduits Beneath Roadways.” National Cooperative Highway Research Program Synthesis of Highway Practice 242, National Academy Press, Washington, D.C., 75 pp.

Johnson, D., and Zollars, J. (1992) “Culvert Renewal,” Minnesota Department of Transportation. Maplewood, Minnesota. 48 pp.

LMK Enterprises, Inc. (2003). “T-Liner Installation Specifications.” Ottawa, Illinois <http://www.lmkenteprises.com/tspec.htm>, 7 pp.

Maine Department of Transportation (2002). “Standard Specifications, SECTION 524-TEMPORARY STRUCTURAL SUPPORTS.” Augusta, Maine. pp. 5-128 to 5-130.

Maryland State Highway Administration (1997). “Protection for Scour and Undermined/Eroded Areas,” Contract No. AA6675180, Category 400 Structures, Sec. 463, 2 pp.

Meacham, D. G., Hurd, J. O., and Shisler, W. W. (1982). *Ohio Culvert Durability Study*. ODOT/L & D/82-1, Ohio Department of Transportation (ODOT), Columbus, OH, 173 pp.

Mobile Area Water and Sewer System (1998). “Rehabilitation of Sanitary Sewer Means by the Cured-In-Place Pipe (CIPP) Method,” Mobile, Alabama <http://mawss.com>, 6 pp.

Multiliner (2004). CIPP Specifications, Abbottsford, British Columbia. <http://www.multiliner.net>, 8 pp.

Najafi, M. (1995). *Trenchless Pipeline Rehabilitation: State of the Art Review*. Sponsored under the U.S. Army Corp of Engineers Construction Productivity Advancement Research (CPAR) Program, Missouri Western State College, St. Joseph, Missouri, 174 pp.

Najafi, M. (2003). “Specifications and Guidelines for Trenchless Technology.” Trenchless Technology Symposium, Midwest Society for Trenchless Technology (MSTT), East Lansing, Michigan, 10 pp.

Norton, J. (2002). “Pipe Coating- A Primer On Types and Applications”, CE News, Chicago, Illinois, pp. 32-35.

Ohio Department of Transportation (1997). “Supplemental Specification 838 Gabions,” Columbus, Ohio, 4 pp.

Ohio Department of Transportation (1999). “Supplemental Specification 837 Liner Pipe,” Columbus, Ohio, 2 pp.

Ohio Department of Transportation (1999). “Supplemental Specification 937; Polyethylene Liner Pipe,” Columbus, Ohio, 1 pp.

Ohio Department of Transportation (2000). “Supplemental Specification 864 Sealing of Concrete Surfaces,” Columbus, Ohio, 5 pp.

Ohio Department of Transportation (2002). “Construction and Material Specifications.” Columbus, Ohio, 1061 pp.

Ohio Department of Transportation (2002). “Supplemental Specification 1066 Plastic Pipe Acceptance Program,” Columbus, Ohio, 6 pp.

Ohio Department of Transportation (2003). *Location and Design Manual*, Vol. II; Drainage Design, Columbus, Ohio, 33 pp.

Ohio Department of Transportation (2004). “Bid tab data”, Office of Estimating. <http://www.odotonline.org/Contracts/Estimating/biddata.asp>, Columbus, Ohio.

Ohio Department of Transportation (2004). “Contracts Awarded for the Calendar Year by Type of Project” <http://www.dot.state.oh.us/Contract/ Estimating/ Summaries/ CY1999-2003/Section2.pdf.>, Columbus, Ohio.

Ohio Department of Transportation (2004). “ODOT Bid Letting Histories.” <ftp://ftp.dot.state.oh.us/Pub/Contracts/ltresults>, Columbus, Ohio.

Perma-Liner Industries, Inc. (2003). “Specifications for Installing Cured-In-Place (CIP) Lateral Lining Inversion Method.” Largo, Florida <http://www.perma-liner.com/pdf/latealspec.pdf.>, 2 pp.

Raven Lining Systems (2003). “Protective and Structural Coatings.” Tulsa, Oklahoma. CD-ROM.

Ray, J. (2002). MUS-70-3.46, MUS-70-12.69, MUS-70-14.45, MUS-70-14.66, PID 20023 Contract Plans, Ohio Department of Transportation, District 5, Jacksontown, Ohio, 21 pp.

Ray, J. (2003). GUE-77-7.10, GUE-77-7.85, GUE-77-11.13, GUE-77-14.43, GUE-77-14.72, PID 21359 Contract Plans, Ohio Department of Transportation, District 5, Jacksontown, Ohio, 12 pp.

Rose, S. (2003). “Polyurethane Chemical Grouting: A Viable Rehab Option.” Trenchless Technology, Volume 12, No. 5, Peninsula, Ohio, 61 pp.

Rush, J. W. (2003). “Trenchless Lateral Replacement.” Trenchless Technology, Volume 12, No. 6, Peninsula, Ohio, pp. 34-36.

Small Structures Committee (2003). *Small Culvert Program*, Indiana Department of Transportation, Indianapolis, Indiana, CD-ROM.

Sturgeon, J. (2004). COL-518-6.18, HOL-514-8.85, PID 21704 Contract Plans, Ohio Department of Transportation, District 11, New Philadelphia, Ohio, 7 pp.

Task Force on Hydrology and Hydraulics AASHTO Subcommittee on Design (1999). AASHTO Highway Drainage Guidelines for Culvert Inspection and Rehabilitation, Volume XIV, American Association of State Highway and Transportation Officials, Washington, D.C., 37 pp.

Thorton, R. (2003). "State of Maryland, Paved Invert Prices", Maryland State Highway Administration, Baltimore, Maryland, 1pp.

Utah Department of Transportation (2002). "Section 02610, PIPE CULVERTS" Specifications, Salt Lake City, Utah, 11 pp.

Vermont Agency of Transportation (2002). Culvert Lining, Proposal, Plans, Photos of VT 105, Bridge #90, Brighton, Vermont.

Vermont Agency of Transportation (2002). Pipe Invert Reconstruction, Proposal, Plans, Photos of Sunderland BR-23 in the town of Sunderland, Vermont on US 7, Bridge #23.

Wyant, D. (2002). "Assessment and Rehabilitation of Existing Culverts, A Synthesis of Highway Practice." National Cooperative Highway Research Program, Synthesis of Highway Practice 303, Transportation Research Board, Washington, D.C., 74 pp.

Zhao, J. Q., and Balvant B. R. (2003). "Cost of Trenchless Projects." Trenchless Technology, Volume12, No.4, Peninsula, Ohio, pp. 27-28.

APPENDIX A:
National Culvert Survey Form

HIGHWAY CULVERTS INSPECTION AND RISK ASSESSMENT SURVEY FORM

The Ohio Department of Transportation (ODOT) has a major research project on highway culvert inspection and risk assessment, which is being conducted by the Ohio Research Institute for Transportation and the Environment (ORITE). The study would greatly benefit from learning how your state DOT is managing highway culverts. We would greatly appreciate your completing this survey form and returning it to ORITE, via regular mail or email. (See contact information at the end). Results will be summarized and presented in the final report of the project. If you have any questions or comments, please contact ORITE.

Question 1: What is your title/position within the DOT?
a) Bridge engineer/inspector
b) Surveyor
c) Hydraulic engineer
d) Maintenance department personnel
d) None of the above (please describe your title/position): ____________________
____
____

Question 2: Who performs the bulk of culvert inspections in your DOT?
a) Highway Workers b) Engineers c) Bridge Crews
d) Other: Specify ___________________________________ e) All of the above

Question 3: Have you personally inspected highway culverts?:
a) Yes b) No

Question 4: Does your DOT address Confined Space issues with regard to culverts?
a) Yes b) No

Question 5: In your state how is highway culvert defined? Highway culverts are defined as a type of bridge whose span is:
a) 6 ft or less b) 8 ft or less
c) 10 ft or less d) 15 ft or less
e) None of the above (please describe your definition): _______________________
____
____
____
____
____
f) I don't know

Question 6: Does your DOT have any inspection policies for highway culverts?:
a) Yes b) No c) I don't know
[Note] Please skip to Question 10 if your answer is b) or c).

Question 7: If yes to Question 6, provide a brief explanation of the inspection guidelines / policy:
____
____
____

Question 8: Does your DOT's culvert inspection policy specify the frequency of inspection?

a) Yes b) No c) I don't know

Question 9: If the answer to Question 8 is Yes, specify the frequency of inspection:

a) less than 1 year b) 1 – 2 years

c) 3-5 years d) more than 5 years

e) Comments: ____

____

____

Question 10: Has your DOT developed a culvert inspection manual?: (If yes, we would appreciate receiving a copy.)

a) Yes b) No c) I don't know

Question 11: Does your DOT apply any numerical rating systems to highway culverts?:

a) Yes b) No c) I don't know

[Note] Please go to Question 14 if your answer is b) or c).

Question 12: Who developed your DOT's culvert numerical rating system?:

a) FHWA b) Your DOT

c) Other (please describe): ____

____

____

d) I don't know

Question 13: Does your DOT have any numerical rating systems for thermoplastic pipe inspection?:

a) Yes (please mention the source): ____

____

b) No c) I don't know

Question 14: Does your DOT utilize the culvert risk assessment method proposed by the NCHRP Report 251?:

a) Yes b) No c) I don't know

[Note] If your answer is a) or c) skip to Question 16.

Question 15: Who developed your DOT's culvert risk assessment system?:

a) Your DOT

b) Other (please describe): ____

____

____

c) I don't know

Question 16: Do you have a computer database for the highway culverts in your state?

a) Yes b) No c) I don't know

[Note] If your answer is a), please describe the database and how it is used: ____________

____

____

____

____

____

Question 17: How does your DOT decide when to replace each highway culvert? (Please mark all that applies).

a) The age of the culvert. (Define):______________________________

b) The sum of numerical rating scores.

c) The deflections experienced by the culvert. (Define):______________________________

d) The degree of culvert material degradation.

e) The roadway surface conditions over the culvert.

f) I am not sure.

g) Primarily by other factors (Please elaborate):______________________________

____

____

Question 18: Does your DOT or the subcontractor that you retain, utilize any special equipment to conduct visual inspections of culverts that are smaller than 4 ft in diameter or rise?

a) Yes b) No c) I don't know

[Note] If your answer is a), please describe the equipment:______________________________

____

____

____

In addition to returning this survey form, we would appreciate receiving copies of any documents (manuals, reports, letters, …) utilized by your DOT that contain information related to the highway culvert inspection & risk assessment policies and procedures.

Ohio Research Institute for Transportation & the Environment (ORITE)
Attention: Highway Culvert Inspection and Risk Assessment Survey
Room 114, Stocker Center
College of Engineering & Technology
Ohio University, Athens, Ohio 45701-2979
Telephone: (740) 593-9547
Fax: (740) 593-0625
e-Mail: orite@bobcat.ent.ohiou.edu
Internet: http://webce.ent.ohiou.edu/orite

Culvert Inspection Survey:

Name of Individual Completing the Survey:______________________________

Title:______________________________

Address:______________________________

____

Telephone Number:______________________________

Email:______________________________

I would like to receive a copy of the survey results: Yes __________ No___________

Thank you for your time and effort in completing this survey.

APPENDIX B:
Proposed Culvert Rating System (Reinforced Concrete Culverts)

CONCRETE CULVERT INSPECTION DATA SHEETS

Project Culvert No. _____: Concrete Culvert No. _____

Inspection Time/Date		
Inspector Names	**(ORITE)**	**(JHA)**

A. Background Information

1	**ODOT District No.**		
2	**County** (Enter code)		Code =
3	**Route**		
4	**Culvert Location** (S.L.M.; GPS; Sta.)		
5	**Functional Classification** (Enter code as well)		Code =
6	**ADT** (Year)		
7	**Concrete Culvert Type** (Enter code)		Code = (Shape) Code = (Material)
8	**Concrete Culvert Size**		
9	**No. of Cells**		
10	**Concrete Culvert Length**	No. of Sections =	
11	**Wall Thickness**		
12	**Culvert Slope (ft/ft)**		
13	**Protective Coating** (Enter code as well)		Code =
14	**Installation Year**		
15	**Year(s) Modified**		
16	**Extension @ Inlet**	**Shape:**	**Material:**
		Size:	**Wall Thickness:**
		Year:	**Length:**
	Extension @ Outlet	**Shape:**	**Material:**
		Size:	**Wall Thickness:**
		Year:	**Length:**
17	**Max. Height of Cover**		
18	**Headwall Type** (Enter code as well)	**@Inlet:**	Code =
		@Outlet:	Code =
19	**Channel Protection**		Code =
20	**Hydraulic Capacity & Pipe Full Velocity (ft/s)***	Hydraulic Capacity = Flow Velocity (fps) =	
		Abrasive Condition? (Y/N):	
21	**Past Inspection Notes & Additional Data**		

[Note] * Based on Manning's formula.

B. Primary Data Collected @ Station ______________________

Describe below the station location with respect to the concrete culvert structure:

ODOT District No.		
County		Code =
Route		
Concrete Culvert Description		Code =
Time/Date of Inspection		

1	**Concrete Surface** (Enter ratings & notes)		**Top (or Slab):**
			Sides (or Abutments):
			Bottom:
2	**Joints** (Enter ratings & notes)		**Top:**
			Sides:
			Bottom:
3	**Invert Paving** (Enter rating & notes)		
4	**Footings** (Enter rating & notes)		
5	**Protective Coating** (Enter rating & notes for each region – top, sides, invert)		**Top:**
			Sides:
			Invert:

[Note] Use multiple copies of this page for recording primary inspection data at additional stations established along the concrete culvert structure.

B. Primary Data Collected – Continued

ODOT District No.		
County		Code =
Route		
Concrete Culvert Description		Code =
Time/Date of Inspection		

6	**Inlet Condition** (Enter rating & notes)		
7	**Outlet Condition** (Enter rating & notes)		
8	**Slope & Settlement (including sagging)** (Enter rating & notes)		
9	**Horizontal Alignment** (Enter rating & notes)		
10	**Additional Data**		

C. Secondary Data Collected

ODOT District No.		
County		Code =
Route		
Concrete Culvert Descript.		Code =
Time/Date of Inspection		

1	**Roadway** (Enter rating & notes for each)		**1.a - Roadway Surface:**
			1.b - Guardrail:
2	**Embankment** (Enter rating & notes for upstream & down-stream slopes)		**Upstream:**
			Downstream:
3a	**Headwall @ Inlet**		**Cracking:**
			Deterioration:
			Movement:
3b	**Headwall @ Outlet**		**Cracking:**
			Deterioration:
			Movement:
4	**Channel** (Enter rating & notes for each of the three factors listed)		**Alignment (4.a):**
			Scour (4.a):
			Obstruction (4.a):
			Protection (4.b):

5	**Drainage Flow**	**Temperature**	˚C
		pH	**(Upstream)**
		DO	**(Upstream)** % of Saturated
		Flow Velocity	**; (Abrasive?)**
		Sample Taken	
6	**Sediment Inside Culvert**	**Description**	
		Depth	
	*** Rating = [ ]**	**Max. Size of Particles/Debris**	
7	**Backfill Soil**	**Relevant Data:**	
8	**Additional Data** ex. Wingwalls (if any)		

D. Photographs Taken

ODOT District No.		
County		Code =
Route		
Concrete Culvert Description		Code =
Time/Date of Inspection		

Type of Camera Used	
Photographer's Name	
Management of Pictures Taken	

E. Level of Inspection

Components	Inlet Section	Outlet Section	Main Barrel
Level of Inspection: Specify --- X = Inspection from ends (no entry) M = Manned entry inspection V = Video inspection			
Type of Video Equipment Used			
Additional Comments			

F. Field Sketches

ODOT District No.			
County			Code =
Route			
Concrete Culvert Description			Code =
Time/Date of Inspection			

Draw sketches in the space below to describe conditions encountered in the field (if necessary):

Primary Data

[B 1] – Concrete Surface

According to ODOT Culvert Inspection Manual (2003; Draft) --- Somewhat Modified.

Rating	Condition
9 (Excellent)	New condition; Superficial & isolated damage from construction.
8 (Very Good)	Discoloration of concrete; Superficial & isolated damage from construction; Minor cracking (without rust staining); No spalling; No scaling.
7 (Good)	Minor hairline cracking at isolated locations (without rust staining); No crack wider than 1/16"; Slight spalling; Light scaling (less than 1/8 in. deep) on invert; Slight loss of mortar; Aggregate not exposed; No concrete softening.
6 (Satisfactory)	Extensive hairline cracks, some with minor delamination or spalling; Moderate loss of mortar around aggregate (aggregate exposed); Invert scaling 1/8 to ¼ in. deep.
5 (Fair)	Cracking open greater than 0.12 in. with moderate delamination and moderate spalling, exposing rebars at isolated locations; Large areas of invert with spalls greater than 0.25 in. depth, significant loss of mortar and slight loss of small aggregates due to surface scaling (1/4 to ½ in. deep).
4 (Poor)	Cracks open more than 0.12 in. with effluence and spalling at numerous locations; Spalls have exposed rebars that are heavily corroded; Heavy invert surface scaling greater than ½ in.; Moderate aggregate loss; concrete softening.
3 (Serious)	Extensive cracking, spalling, and minor slabbing; Invert scaling has exposed rebars at isolated locations; Moderate amount of concrete softening.
2 (Critical)	Extensive cracking with spalling, delaminations; Severe slabbing has occurred at isolated locations; invert scaling below the first layer of rebars; 50% loss of wall thickness at invert or top; concrete very soft.
1 (Failure Imminent)	Holes through in concrete at isolated locations; 75% loss of wall thickness at invert; rebars exposed throughout invert; Culvert collapse is imminent.
0 (Failed)	Invert completely deteriorated; even rebars gone; Culvert has collapsed.

[B 2] – Joints (Opening, Cracks)

According to ODOT Culvert Inspection Manual (2003; Draft).

Rating	Condition
9 (Excellent)	New condition.
8 (Very Good)	Tight with no apparent defects; Minor misalignment/settlement at joints.
7 (Good)	Minor misalignment/settlement at joints; Offsets less than ½"; Minor openings; possible soil infiltration/ exfiltration; Minor distress to material adjacent to joint; Shallow mortar deterioration at isolated locations.
6 (Satisfactory)	Minor backfill infiltration due to slight opening at joints; Minor cracking or spalling at joints allowing exfiltration; Slightly dislocated end section; Extensive area of shallow mortar deterioration; Joint offsets less than 1".
5 (Fair)	Joint open and allowing backfill to infiltrate; Significant cracking or joint spalling; Joint offsets less than 3"; End section dislocated; Mortar generally deteriorated (loose or missing mortar at isolated locations).
4 (Poor)	Differential movement and separation of joints; Significant infiltration or exfiltration at joints; Joint offsets less than 4"; Voids seen in fill through offset joints; End section dislocated; Significant loss of mortar.
3 (Serious)	Significant openings; Dislocated joints in several locations, exposing fill material; Infiltration or exfiltration, causing misalignment of pipe and settlement or depressions in roadway; Joint offsets more than 4"; Voids seen in fill through offset joints; End section dropping off.
2 (Critical)	Culvert is not functioning due to alignment problems throughout; Large voids seen in fill through offset joints.
1 (Failure Imminent)	Culvert has failed partially or collapse is imminent.
0 (Failed)	Culvert has collapsed.

Primary Data

[B 3] – Invert Paving

(See the rating system for B5 – Protective Coating).

[B 4] – Footings

According to ODOT Culvert Inspection Manual (1990).

Rating	Descriptions
9 (Excellent)	New condition.
8 (Very Good)	Good with no erosion.
7 (Good)	Moderate erosion, causing differential settlement and minor cracking in footing.
6 (Fair)	Moderate cracking and differential settlement of footing due to extensive erosion.
5 (Fair-Marginal)	Significant undercutting of footing and extreme differential settlement; Major cracking in footing.
4 (Marginal)	Rotated due to erosion and undercutting; settlement has caused damage to culvert.
3 (Poor)	Rotated; severely undercut; Major cracking and spalling.
2 (Very Poor)	Severe differential settlement has caused distortion and kinking of culvert.
1 (Failure)	Culvert has partially failed or collapse is imminent.
0 (Failure)	Culvert has failed completely.

[B 5] – Protective Coating

Rating	Descriptions
9 (Excellent)	Good, intact; No signs of delamination.
8 (Very Good)	Generally good; intact; Minor delamination (hairline cracks) at one location.
7 (Good)	Minor delamination (hairline cracks) of coating at isolated locations.
6 (Fair)	Minor delamination (hairline cracks) of coating at numerous locations.
5 (Fair-Marginal)	Moderate delamination (extensive cracking & peeling) of coating at a few isolated locations as well as minor delamination (hairline cracks) at numerous locations.
4 (Marginal)	Moderate delamination (extensive cracking & peeling) at numerous locations.
3 (Poor)	Coating removed over a large area at isolated locations.
2 (Very Poor)	Coating removed over a large area at numerous locations.
1 (Failure)	Culvert has partially collapsed or collapse is imminent.
0 (Failure)	Culvert has failed completely.

[B 6 & 7] – Inlet & Outlet Conditions

Rating	Condition
9 (Excellent)	New condition.
8 (Very Good)	Good, no signs of material deteriorations (no cracking, no spalling, no scaling); No movement (dropping off or lifting up) of the culvert end; No scouring underneath.
7 (Good)	Signs of minor material deterioration (cracking, spalling, scaling); No movement (dropping off or lifting up) of the culvert end; Minor scouring at the end.
6 (Fair)	Signs of minor material deterioration (cracking, spalling, scaling), Minor movement (dropping off or lifting up) of the culvert end; Minor scouring at the end.
5 (Fair-Marginal)	Moderate deterioration of the culvert material (cracking, spalling, scaling), Minor movement of the pipe end; Moderate scouring at the end.
4 (Marginal)	?
3 (Poor)	Moderate deterioration of the culvert material (cracking, spalling, scaling); Moderate movement of the pipe end; Moderate scouring at the end.
2 (Very Poor)	Significant degradation of the culvert material (cracking, spalling, scaling); Severe movement of the end; Severe scouring at the end at the end.
1 (Critical)	Culvert has partially collapsed or collapse is imminent.
0 (Failure)	Total failure of the culvert and fill.

[Note] End section is defined as the first/last 5’ section of the culvert structure, unless …

Primary Data

[B 8] – Slope & Settlement

According to ODOT Culvert Inspection Manual (2003; Draft) – Modified slightly.

Rating	Descriptions
9 (Excellent)	Like new; Good; uniform slope; no settlement.
8 (Very Good)	Minor settlement at one location.
7 (Good)	Minor settlement at isolated locations; Offsets at joints less than ½"; Ponding water less than 1" deep.
6 (Fair)	Minor settlement at numerous locations along the culvert; Ponding water less than 3" deep.
5 (Fair-Marginal)	Moderate settlement at one location; Offsets at joints less than 3"; Ponding water less than 5."
4 (Marginal)	Moderate settlement of the culvert; Ponding water less than 6" deep; 4 or more sections with offsets less than 3"; End section dislocated and about to drop off.
3 (Poor)	Severe settlement in one section; Ponding water deeper than 6"; End section dropping off; 4 or more sections with offsets less than 4."
2 (Very Poor)	Culvert not functioning due to sever settlement problem; Upstream end cannot be seen from the downstream end; Ponding of water more than 50% of the pipe length.
1 (Critical)	Culvert has partially collapsed.
0 (Failure)	Culvert has collapsed completely.

[B 9] – Horizontal Alignment

Rating	Descriptions
9 (Excellent)	New condition.
8 (Very Good)	Good: no horizontal misalignment.
7 (Good)	Generally good; minor misalignment at one location; No backfill infiltration problem exists yet.
6 (Fair)	Generally fair; minor misalignment at isolated locations; No backfill infiltration problem exists yet.
5 (Fair-Marginal)	Moderate misalignment at one location; Minor backfill infiltration may be possible there.
4 (Marginal)	Moderate misalignment at isolated locations; Minor backfill infiltration may be possible.
3 (Poor)	Significant misalignment of the culvert at isolated locations; End section drop-off has occurred; Minor backfill infiltration is observed.
2 (Very Poor)	Culvert not functioning due to severe alignment problems throughout; Signs of backfill infiltration seen at more than a few locations.
1 (Critical)	Culvert has failed partially or collapse is imminent.
0 (Failure)	Culvert has collapsed completely.

Secondary Data

[C 1.a] – Roadway Surface

According to ODOT Culvert Inspection Manual (2003; Draft) – Modified somewhat.

Rating	Descriptions
9 (Excellent)	New condition; No defects noticed.
8 (Very good)	Minor hairline cracks; No dip (settlement).
7 (Good)	Minor hairline cracks; Minor scaling; Very small potholes; No dip (settlement).
6 (Satisfactory)	Minor potholes; Minor dip (settlement); Cracking with width less than 0.1 in; Transverse cracks do not extend all the way across the roadway.
5 (Fair)	Moderate size potholes; Minor spalling; Minor dip accompanied with a few cracks; Transverse cracks are wider than 0.1 in and extend all the way across the roadway.
4 (Poor)	Moderate dip in roadway; Numerous cracks on the surface layer (starting to break up the pavement).
3 (Serious)	Significant dip; Extensive cracking of roadway surface (breaking up the pavement); Repairs required immediately.
2 (Critical)	Significant dip; Extensive cracking of roadway surface, damages on the pavement surface layer, posing potential danger to drivers; Embankment washed out next to pavement.
1 (Closed)	Road closed; Impending pavement and/or embankment failure.
0 (Failed)	Roadway is closed to traffic; Embankment and/or pavement failed.
- 1	Cannot be rated; Roadway is still under construction.

[C 1.b] – Guardrail

According to ODOT Culvert Inspection Manual (2003; Draft)

Rating	Descriptions
9 (Excellent)	New condition; Guardrail free from any defects.
8 (Very good)	Minor discoloration; No noteworthy deficiencies noted;
7 (Good)	Minor deficiencies noted within 100’ of culvert; No bolts missing; Misalignment of 1 or 2 guardrail posts.
6 (Satisfactory)	Minor collision damage; Up to 10% loss of section of posts due to decay; Guardrail position is noticeably higher or lower than the standard 27”; Guardrail panels are rusted; Several bolts are missing; Misalignment of up to 3 guardrail posts.
5 (Fair)	Moderate collision damage; Up to 20% loss of section of posts due to decay; Guardrail position is noticeably higher or lower than the standard 27”; Guardrail panels are rusted; Several bolts are missing; Misalignment of up to 5 guardrail posts.
4 (Poor)	Major collision damage; Up to 30% loss of section of posts due to decay; Guardrail position is noticeably higher or lower than the standard 27”; Guardrail panels are rusted; Several bolts are missing; Misalignment of up to 6 guardrail posts.
3 (Serious)	Major collision damage; Up to 50% loss of section of posts due to decay; Guardrail position is noticeably higher or lower than the standard 27”; Guardrail panels are rusted; Several bolts are missing; Misalignment of more than 6 guardrail posts.
2 (Critical)	Guardrail is not functioning; Up to 90% of decay of posts.
1 (Closed)	Guardrail has collapsed partially.
0 (Failed)	Guardrail has collapsed completely.
- 1	Cannot be rated; Guardrail is still under construction.

Secondary Data

[C 2] – Embankment (Apply to Upstream & Downstream Slopes Separately)

According to ODOT Culvert Inspection Manual (2003; Draft) – Modified slightly.

Rating	Descriptions
9 (Excellent)	No noteworthy conditions detected on embankment slopes within 100' of culvert.
8 (Very Good)	Minor erosion in one area away from the culvert; Vegetation intact.
7 (Good)	Minor erosion in isolated areas (bare soil exposed slightly) away from the structure, No threats to the culvert and headwall.
6 (Satisfactory)	Moderate erosion in one area away from the structure; Soils exposed in the area; No threats to the culvert and headwall.
5 (Fair)	Moderate erosion in isolated areas, mostly away from the structure; Soils exposed & guardrail impacted in the area; Minor erosion behind the headwall; No cracks on the headwall.
4 (Poor)	Erosion impacting guardrail performance; Moderate erosion behind the headwall; Slope stability problem found in isolated areas; Minor hairline cracks on the head-wall; Slight movement of the headwall.
3 (Serious)	Slope stability problem at isolated locations (eroding way the shoulder section of the roadway); Severe erosion behind the headwall; It has caused extensive hairline cracks and/or a moderate movement (ex. tilting) on the headwall.
2 (Critical)	Severe erosion taking place, causing damage to the roadway shoulder section; headwall has physical damages (ex. severe cracks) and tilted significantly.
1 (Imminent Failure)	One lane of traffic is closed due to embankment failure; Several guardrail posts are hanging in the air due to major erosion and/or slope stability problem.
0 (Failed)	Embankment has collapsed (can lead to the loss of culvert).
- 1	Cannot be rated; Embankment is still under construction.

Secondary Data

[C 3] – Headwall/Wingwall (Apply to Inlet & Outlet Separately)

Rating	**Descriptions for:**		
	Cracking	**Deterioration (Spalling, Delamination, …)**	**Movement (Settlement, Rotation, …)**
9 (Excellent)	New condition.	New condition.	New condition.
8 (Very Good)	Aged concrete; Some discoloration; No cracks.	No signs of material deterioration. Minor discoloration.	No movement.
7 (Good)	A few to several hairline cracks detected.	Light scaling (less than 1/8 in deep); Slight loss of mortar. Aggregates not exposed.	Slight movement on one side (or in one area).
6 (Satisfactory)	Extensive hairline cracking. No rebars exposed.	Minor delamination or spalling along cracks. Surface scaling 1/8 to 1/4 in deep. Some small aggregates lost.	Slight movement on both sides.
5 (Fair)	One of the cracks is at least 0.1 inch wide.	Moderate delamination, Moderate spalling. Rebars beginning to surface.	Moderate movement on one side (or in one area).
4 (Poor)	A few major cracks in addition to some hairline cracks.	Moderate spalling/scaling at isolated locations. One side of the first layer of rebars exposed .	Moderate movement on both sides.
3 (Serious)	Several major cracks running through the wall.	Moderate scaling has occurred at many locations. First layer of rebars exposed completely. Moderate degree of concrete softening.	Severe movement on one side (or in one area). Rotation up to 4" per foot.
2 (Critical)	Numerous major cracks. Some regions are becoming almost loose.	Severe spalling/scaling has occurred extensively.	Severe movement on both sides.
1 (Critical)	Major portion of the headwall gone; Rebars exposed extensively and corroded severely.		Headwall has partially failed.
0 (Failure)	Headwall has collapsed completely.		

Secondary Data

[C 4.a] – Channel (General)

According to ODOT Culvert Inspection Manual (Draft 2003) – Modified Slightly.

Rating	Descriptions for:		
	Alignment	**Scouring**	**Obstruction**
9 (Excellent)	New conditions. Channel is straight for more than 100' at both upstream & downstream. No adverse conditions detected.	New conditions. No scouring at either inlet or outlet ends.	New conditions. No debris or sediment accumulation anywhere.
8 (Very Good)	Channel straight for 50' to 100' at one end, for more than 100' at other end.	Very minor (< 6" deep) scouring at both inlet and outlet ends.	Minor debris accumulation.
7 (Good)	Channel is straight for 50' to 100' at both ends; Minor sediment accumulation; Bush growing.	Minor (6" to 12" deep) scouring at one end.	Minor sedimentation and debris accumulation; Up to 5% blockage of channel opening.
6 (Satisfactory)	Channel is straight for 20' to 50' at one end; Channel is curved by 20˚ to 40˚ angle near inlet; Deposit causing channel to split.	Minor (6" to 12" deep) scouring at both ends; Top of footings is exposed.	Minor sedimentation and debris. Up to 10% blockage of channel opening; Bush or tree growing in channel.
5 (Fair)	Channel is straight for 20' to 50' at both ends; Channel curved by 40˚ to 50˚ angle near inlet; Flow hitting outside headwall; Stream meandered; Signs of Bank erosion.	Minor (6" to 12" deep) scouring at one end; Moderate (12" to 24" deep) scouring at the other end; Footings along the side are exposed.	Waterway moderately (up to 25%) restricted by tree, shrubs, or sedimentation; Bush or tree growing in channel.
4 (Poor)	Channel curved by 50˚ to 70˚ angle near inlet; Flow enters culvert by other means than design opening; Signs of Bank erosion.	Severe (2' to 3' deep) scouring at one end; Less scouring at the other end; Bottom of footings is exposed; Not undermining cutoff walls/headwalls.	Partial (up to 50%) blockage of channel opening; Large debris in the waterway; Occasional overtopping of roadway.
3 (Serious)	Channel curved by 70˚ to 90˚ turn near inlet; Erosion behind wingwalls; Erosion of embankment encroaching on roadway.	Major (> 3' deep) scouring at one end; Cutoff walls and/or headwalls being undermined; Footings are undermined; Structure has been displaced or settled.	Mass drift accumulation has restricted 75% of channel opening; Occasional overtopping of roadway.
2 (Critical)	Channel flow piping around culvert; Erosion of embankment encroaching on roadway.	Structure or roadway weakened by bank erosion or scour problem; danger of collapse sometime in the future.	Culvert waterway blocked up to 85% by mass drift accumulation; Frequent overtopping of roadway w/ significant traffic delays.
1 (Failure Imminent)	No channel flow enters culvert; Severe piping problem around culvert; Road may be closed due to channel failure.	Structure or approach weakened; danger of immediate collapse.	Culvert waterway 100% blocked by deposits; Water pooling outside and not flowing through pipe; Road may be closed due to channel failure.
0 (Failed)	Pipe has collapsed.	Pipe has collapsed.	Pipe has collapsed.
- 1 (Under Construction)	Cannot be rated; still under construction.		

[C 4.b] Channel (Protection)

According to ODOT Culvert Inspection Manual (2003; Draft)

Rating	Descriptions
9 (Excellent)	Channel protections are not required or are in a stable condition.
8 (Very Good)	No noteworthy deficiencies that affect the channel protection; Banks are protected or well vegetated.
7 (Good)	Channel bank is beginning to slump; Embankment protection has minor damage; Bank protection is in need of minor repairs.
6 (Satisfactory)	Riprap starting to wash away; Cracked concrete channel protection at inlet.
5 (Fair)	Broken up concrete channel protection at inlet; Bank protection has eroded.
4 (Poor)	Channel protection is severely undermined; Stone is completely washed away; Major erosion; Failed concrete channel protection at inlet; Bank or embankment protection is severely undermined.
3 (Serious)	Channel protection has failed; Channel has moved to where the culvert and approach roadway are threatened.
2 (Critical)	Channel protection has failed; Channel flow is causing major scour effects.
1 (Imminent Failure)	Culvert closed because of channel failure.
0 (Failed)	Culvert has collapsed completely.

[C6] Sediment Inside Culvert

Rating	Descriptions
9 (Excellent)	New condition; No sediment accumulation at all.
8 (Very Good)	Less than 0.5 in. deep sediment accumulation inside the culvert; Sediment has no impact on drainage flow.
7 (Good)	0.5 to 2 in. deep sediment accumulation inside the culvert; or Up to 5% of the culvert opening is filled with sediment ; Sediment has little impact on drainage flow.
6 (Satisfactory)	2 to 4 in. deep sediment accumulation inside the culvert; or Up to 10% of the culvert opening is filled with sediment
5 (Fair)	4 to 6 in. deep sediment accumulation inside the culvert; or Up to 25% of the culvert opening is filled with sediment
4 (Poor)	Sediment accumulation up to 12 in. in some areas inside the culvert; or Up to 35% of the culvert opening is filled with sediment Sedimentation begins to affect the drainage flow through the culvert.
3 (Serious)	Sediment accumulation up to 24 in. in some areas inside the culvert; or Up to 50% of the culvert opening is filled with sediment
2 (Critical)	Sediment accumulation up to 36 in. in some areas inside the culvert; or Up to 65% of the culvert opening is filled with sediment
1 (Imminent Failure)	Sediment accumulation is more than 36 in. inside the culvert; Up to 80% of the culvert opening is filled with sediment; Hydraulic function of the original culvert has been severely diminished.
0 (Not Functioning)	The culvert is silted up with sediment all the way. The culvert is not functioning as a drainage structure.

APPENDIX C:
Proposed Culvert Rating System (Corrugated Metal Culverts)

METAL CULVERT INSPECTION DATA SHEETS
Project Culvert No. ____ : Metal Culvert No. ______

Inspection Time/Date		
Inspector Names	**(ORITE)**	**(JHA)**

A. Background Information

1	**ODOT District No.**			
2	**County** (Enter code)			Code =
3	**Route**			
4	**Culvert Location** (S.L.M.; GPS; Sta.)			
5	**Functional Classif.** (Enter code)			Code =
6	**ADT** (Year)			
7	**Metal Culvert Type** (Enter code; mention also pipe material)			Code = (Shape) Code = (Material)
8	**Metal Culvert Size**			
9	**No. of Cells**			
10	**Metal Culvert Length**			
11	**Culvert Slope (ft/ft)**			
12	**Corrugation Size & Thickness (Gauge)**	**Pitch:**	**Depth:**	
		Gauge:	inches	Code =
13	**Protective Coating** (Enter code as well)			Code =
14	**Installation Year**			
15	**Year(s) Modified**			
16	**Extension @ Inlet**	**Shape:**	**Material:**	
		Size:	**Wall Thickness:**	
		Year:	**Length:**	
	Extension @ Outlet	**Shape:**	**Material:**	
		Size:	**Wall Thickness:**	
		Year:	**Length:**	
17	**Max. Height of Cover**			
18	**Headwall Type** (Enter code as well)	**@ Inlet:**		Code =
		@ Outlet:		Code =
19	**Channel Protection**			Code =
20	**Hydraulic Capacity & Pipe Full Velocity (ft/s)***	**Hydraulic Capacity =** **Flow Velocity (fps) =**		
		Abrasive Condition (Y/N)?:		
21	**Past Inspection Notes & Additional Data**			

[Note] * Based on Manning's formula.

B. Primary Data Collected @ Station ____________________

Describe below the station location with respect to the metal pipe culvert structure:

ODOT District No.		
County		Code =
Route		
Metal Culvert Description		Code =
Time/Date of Inspection		

1	**Span & Rise Dimension**	**Span =** **Rise =**	
2	**Other Dimensions** (ex. top-arc mid ordinate, …)		
3	**Shape Observations** (Enter rating & note)		
4	**Deflection** (Enter rating & note)		
5	**Metal Plate** (Enter ratings & notes for each region – top, sides, and invert)		**Top:**
			Sides:
			Invert:
	Prospector's Pick Observation		
6	**Joints & Seams** (Enter ratings & notes for each region – top, sides, invert)		**Top:**
			Sides:
			Invert:
7	**Protective Coating** (Enter rating & notes)		
8	**Invert Paving** (Enter rating & notes)		
9	**Footings** (Enter rating & notes)		

[Note] Use multiple copies of this page for recording primary inspection data at additional stations established along the metal culvert structure.

B. Primary Data Collected – Continued

ODOT District No.		
County		Code =
Route		
Metal Culvert Description		Code =
Time/Date of Inspection		

10	**Inlet Condition** (Enter rating & notes)		
11	**Outlet Condition** (Enter rating & notes)		
12	**Slope & Settlement (including sagging)** (Enter rating & notes)		
13	**Horizontal Alignment** (Enter rating & notes)		
14	**Additional Data**		

C. Secondary Data Collected

ODOT District No.		
County		Code =
Route		
Metal Culvert Description		Code =
Time/Date of Inspection		

1	**Roadway Surface** (Enter rating & notes for each item)		**Surface (1.a):**
			Guardrail (1.b):
2	**Embankment** (Enter rating & notes for up-stream and downstream side slopes)		**Upstream:**
			Downstream:
3a	**Headwall @ Inlet** (Enter rating & notes for each category)		**Cracking:**
			Deterioration:
			Movement:
3b	**Headwall @ Outlet** (Enter rating & notes for each category)		**Cracking:**
			Deterioration:
			Movement:
4	**Channel** (Outside the culvert; Enter rating & notes for each of the three factors listed)		**Alignment (4.a):**
			Scour (4.a):
			Obstruction (4.a):
			Protection (4.b):

5	**Drainage Flow**	**Temperature**	**(Upstream):** ˚C
		pH	**(Upstream):**
		DO	**(Upstream):** % of Saturated
		Flow Velocity	**(Abrasive?)**
		Sample Taken	
6	**Sediment Inside Culvert** * **Rating = [ ]**	Description	
		Depth	
		Max. Size of Particles/Debris	
7	**Backfill Soil**	**Any Relevant Data:**	
8	**Metal Plate**	Coupons Taken	

C. Secondary Data Collected

ODOT District No.		
County		Code =
Route		
Metal Culvert Description		Code =
Time/Date of Inspection		

Additional Data	

D. Photographs Taken

Type of Camera Used	
Photographer's Name	
Management of Pictures Taken	

E. Level of Inspection

Components	Inlet Section	Outlet Section	Main Barrel
Level of Inspection: Specify --- X = Inspection from ends (no entry) M = Manned entry inspection V = Video inspection			
Type of Video Equipment Used			
Additional Comments			

F. Field Sketches

ODOT District No.		
County		Code =
Route		
Metal Culvert Description		Code =
Time/Date of Inspection		

Draw sketches in the space below to describe conditions encountered in the field (if necessary):

Primary Data

[B 3] – Shape

According to ODOT Culvert Inspection Manual (2003; Draft).

Rating	Descriptions
9 (Excellent)	New condition.
8 (Very Good)	Good with smooth curvature.
7 (Good)	Smooth curvature in top half; Bottom flattened but still curved.
6 (Satisfactory)	Smooth curvature in top half; Bottom flat.
5 (Fair)	Significant distortion in top arch at one location; Bottom has slight reverse curvature in one location but is generally smooth.
4 (Poor)	Significant distortion in the top arch throughout culvert; Lower third may be kinked; Bottom has reverse curvature.
3 (Serious)	Extreme deflection in top arch at isolated locations; Extreme non-symmetric shape; Significant flattening of top arch; Bottom has reverse curvature throughout.
2 (Critical)	Extreme distortion/deflection along top of arch throughout culvert.
1 (Failure Imminent)	Culvert has partially collapsed. Reversal of curvature appearing at the crown.
0 (Failed)	Culvert has collapsed completely.

[B 4] – Deflection (Vertical)

According to ODOT Culvert Inspection Manual (2003; Draft).

Rating	Descriptions
9 (Excellent)	New condition.
8 (Very Good)	Within 1% of design.
7 (Good)	Within 2.5% of design.
6 (Satisfactory)	Within 5% of design.
5 (Fair)	Within 10% of design.
4 (Poor)	Within 15% of design.
3 (Serious)	Between 15% and 20% of design.
2 (Critical)	More than 20% of design.
1 (Failure Imminent)	Culvert has partially collapsed; Reversal of curvature appearing at the crown.
0 (Failed)	Culvert has collapsed completely.

<Note> The design value may be assumed to be equal to 5% when it is not available.

[B 5] – Metal Plate Surface

Rating	Descriptions
9 (Excellent)	New condition; metal coating intact; No corrosion.
8 (Very Good)	Discoloration of surface; Metal coating partially gone.
7 (Good)	Discoloration of surface; Superficial or pinpoint rust spots; No pitting; No pinholes.
6 (Satisfactory)	Moderate rust; Rust flakes tight; Shallow pitting of surface; Metal coating gone; No pinholes.
5 (Fair)	Heavy rust and scale; Moderate pitting and slight thinning of core metal; Core metal loss up to 10%; No perforations; Pinholes found along culvert.
4 (Poor)	Extensive heavy rust; Thick and scaling rust coatings throughout culvert; Deep pitting; Significant core metal loss (up to 25%); No perforations.
3 (Serious)	Rust and pitting halfway through core metal; Scattered perforations; Significant core metal loss (up to 50%); Thin metal can be punctured easily by pick.
2 (Critical)	Extreme deterioration and pitting; 75% of core metal gone; Extensive perforations appearing; Thin metal can be punctured easily by pick.
1 (Failure Imminent)	Extensive and large perforations; Invert or other section completely deteriorated; Culvert collapse is imminent.
0 (Failed)	Invert completely deteriorated; Culvert has collapsed completely.

Primary Data

[B 6] – Joints & Seams

According to ODOT Culvert Inspection Manual (1990).

Rating	Descriptions
9 (Excellent)	New condition.
8 (Very Good)	Good condition; Minor discoloration; Light surface rust around bolt holes due to loss of metal coating.
7 (Good)	Rust scale around bolt holes; Minor cracking at a few bolt holes; Minor (< 1/8") joint or seam openings; Seepage infiltration (dripping water droplets) noted; More than 2 missing bolts per row.
6 (Satisfactory)	Minor cracking all along one seam; Joint openings (up to ¼") with evidence of seepage infiltration and slight backfill infiltration; Superficial rusting of the plates & bolts; More than 4 missing bolts per row.
5 (Fair)	Moderate cracking at bolt holes along a seam in one section; Backfill being lost through seam or joint, causing slight deflection; Moderate rusting of plates & bolts; More than 6 missing bolts per row.
4 (Poor)	Moderate cracking all along one seam; Backfill infiltration causing major deflection; Moderate rusting of plates & bolts at the joint; Partial cocked and cusped seams; 10% of bolts missing along seams.
3 (Serious)	Seam cracked 3 inches on each side of bolt holes along culvert; Longitudinal cocked & cusped seams; Backfill infiltrating.
2 (Critical)	Seam cracked from bolt to bolt down at least one seam. Heavy rusting of plates & bolts; Significant amounts of backfill infiltration.
1 (Failure Imminent)	Seam failed totally; Backfill exposed; Water flowing out of the culvert.
0 (Failed)	Culvert has collapsed completely.

[B 7] – Protective Coating

Rating	Descriptions
9 (Excellent)	New condition; Intact; No signs of delamination.
8 (Very Good)	Mostly intact; Minor delamination (hairline cracks) at one location.
7 (Good)	Minor delamination (hairline cracks) of coating at isolated locations.
6 (Fair)	Minor delamination (hairline cracks) of coating at numerous locations.
5 (Fair-Marginal)	Moderate delamination (extensive cracking & peeling) of coating at a few isolated locations as well as minor delamination (hairline cracks) at numerous locations.
4 (Marginal)	Moderate delamination (extensive cracking & peeling) at numerous locations.
3 (Poor)	Coating removed over a large area at isolated locations.
2 (Very Poor)	Coating removed over a large area at numerous locations.
1 (Failure Imminent)	Culvert has partially collapsed or collapse is imminent.
0 (Failure)	Culvert has failed completely.

[B 8] – Invert Paving

(See the rating system for B7 - Protective Coating).

Primary Data

[B 9] – Footings

According to ODOT Culvert Inspection Manual (1990).

Rating	Descriptions
9 (Excellent)	New condition.
8 (Very Good)	Good with no erosion.
7 (Good)	Moderate erosion, causing differential settlement and minor cracking in footing.
6 (Fair)	Moderate cracking and differential settlement of footing due to extensive erosion.
5 (Fair-Marginal)	Significant undercutting of footing and extreme differential settlement; Major cracking in footing.
4 (Marginal)	Rotated due to erosion and undercutting; Settlement has caused damage to culvert.
3 (Poor)	Rotated; severely undercut; Major cracking and spalling.
2 (Very Poor)	Severe differential settlement has caused distortion and kinking of culvert.
1 (Failure Imminent)	Culvert has partially failed or the failure is imminent.
0 (Failure)	Culvert has failed completely.

Primary Data

[B 10 & 11] – Inlet & Outlet Conditions

Rating	Descriptions
9 (Excellent)	New condition.
8 (Very Good)	Slight discoloration; No signs of corrosion; No pitting; No damage on the culvert end from falling/moving debris; No movement (dropping off or lifting up) of the culvert end; No scouring underneath.
7 (Good)	Signs of light corrosion; Slight pitting; No damage on the culvert end; No movement (dropping off or lifting up) of the culvert end; No scouring underneath.
6 (Fair)	Signs of light material deterioration (corrosion, pitting); A few small pinholes/ perforations; culvert end slightly damaged; Minor movement (dropping off or lifting up) of the culvert end; Minor scouring at the end.
5 (Fair-Marginal)	Moderate deterioration (corrosion, pitting) of the culvert material; Small perforations at several isolated places; Culvert end moderately damaged; Minor movement of the culvert end; Moderate scouring at the end.
4 (Marginal)	Moderate deterioration of the culvert material; Medium-size perforations at numerous locations; Minor movement of the culvert end; Moderate scouring at the end and/or underneath the culvert.
3 (Poor)	Severe deterioration (corrosion, pitting) of the culvert material; Large perforations; Moderate movement of the culvert end; Moderate scouring at the end and/or underneath the culvert.
2 (Very Poor)	Significant degradation of the culvert material (leading to some perforations); Severe movement of the end; A sizable portion of the end is torn off (changing the course of drainage flow); Severe scouring at the end and/or underneath the culvert.
1 (Critical)	Culvert has collapsed partially.
0 (Failure)	Culvert has collapsed completely.

[B 12] – Slope & Settlement

According to ODOT Culvert Inspection Manual (2003; Draft) – Modified slightly.

Rating	Descriptions
9 (Excellent)	Like new; Good; uniform slope; no settlement.
8 (Very Good)	Minor settlement at one location.
7 (Good)	Minor settlement at isolated locations; Offsets at joints less than ½”; Ponding water less than 1” deep.
6 (Fair)	Minor settlement at numerous locations along the culvert; Ponding water less than 3” deep.
5 (Fair-Marginal)	Moderate settlement at one location; Offsets at joints less than 3”; Ponding water less than 5.”
4 (Marginal)	Moderate settlement of the culvert; Ponding water less than 6” deep; 4 or more sections with offsets less than 3”; End section dislocated and about to drop off.
3 (Poor)	Severe settlement in one section; Ponding water deeper than 6”; End section dropping off; 4 or more sections with offsets less than 4.”
2 (Very Poor)	Culvert not functioning due to sever settlement problem; Upstream end cannot be seen from the downstream end; Ponding of water more than 50% of the pipe length.
1 (Critical)	Culvert has partially collapsed.
0 (Failure)	Culvert has collapsed completely.

Primary Data

[B 13] – Horizontal Alignment

Rating	Descriptions
9 (Excellent)	New condition.
8 (Very Good)	Very minor horizontal misalignment.
7 (Good)	Minor misalignment at one location; No backfill infiltration problem exists yet.
6 (Fair)	Minor misalignment at isolated locations; No backfill infiltration problem exists yet.
5 (Fair-Marginal)	Moderate misalignment at one location; Minor backfill infiltration may be possible there.
4 (Marginal)	Moderate misalignment at isolated locations; Minor backfill infiltration may be possible.
3 (Poor)	Significant misalignment of the culvert at isolated locations; Minor backfill infiltration is observed.
2 (Very Poor)	Culvert not functioning due to severe alignment problems throughout; Signs of backfill infiltration seen at more than a few locations.
1 (Critical)	Culvert has failed partially.
0 (Failure)	Culvert has collapsed completely.

Secondary Data

[C 1.a] – Roadway Surface

According to ODOT Culvert Inspection Manual (2003; Draft) – Modified somewhat.

Rating	Descriptions
9 (Excellent)	New condition; no defects noticed.
8 (Very good)	Minor hairline cracks; No dip (settlement).
7 (Good)	Minor hairline cracks; Minor scaling; Very small potholes; No dip (settlement).
6 (Satisfactory)	Minor potholes; Minor dip (settlement); cracking with width less than 0.1 in; Transverse cracks do not extend all the way across the roadway.
5 (Fair)	Moderate size potholes; Minor spalling; Minor dip accompanied with a few cracks; Transverse cracks are wider than 0.1 in and extend all the way across the roadway.
4 (Poor)	Moderate dip in roadway; Numerous cracks on the surface layer (starting to break up the pavement).
3 (Serious)	Significant dip; Extensive cracking of roadway surface (breaking up the pavement); Repairs required immediately.
2 (Critical)	Significant dip; Extensive cracking of roadway surface, Damages on the pavement surface layer, posing potential danger to drivers; Embankment washed out next to pavement.
1 (Closed)	Road closed; Impending pavement and/or embankment failure.
0 (Failed)	Roadway is closed to traffic; Embankment and/or pavement failed.
- 1	Cannot be rated; Roadway is still under construction.

[C 1.b] – Guardrail

According to ODOT Culvert Inspection Manual (2003; Draft)

Rating	Descriptions
9 (Excellent)	New condition; Guardrail free from any defects.
8 (Very good)	Minor discoloration; No noteworthy deficiencies noted;
7 (Good)	Minor deficiencies noted within 100' of culvert; No bolts missing; Misalignment of 1 or 2 guardrail posts.
6 (Satisfactory)	Minor collision damage; Up to 10% loss of section of posts due to decay; Guardrail position is noticeably higher or lower than the standard 27"; Guardrail panels are rusted; Several bolts are missing; Misalignment of up to 3 guardrail posts.
5 (Fair)	Moderate collision damage; Up to 20% loss of section of posts due to decay; Guardrail position is noticeably higher or lower than the standard 27"; Guardrail panels are rusted; Several bolts are missing; Misalignment of up to 5 guardrail posts.
4 (Poor)	Major collision damage; Up to 30% loss of section of posts due to decay; Guardrail position is noticeably higher or lower than the standard 27"; Guardrail panels are rusted; Several bolts are missing; Misalignment of up to 6 guardrail posts.
3 (Serious)	Major collision damage; Up to 50% loss of section of posts due to decay; Guardrail position is noticeably higher or lower than the standard 27"; Guardrail panels are rusted; Several bolts are missing; Misalignment of more than 6 guardrail posts.
2 (Critical)	Guardrail is not functioning; Up to 90% of decay of posts.
1 (Closed)	Guardrail has collapsed partially.
0 (Failed)	Guardrail has collapsed completely.
- 1	Cannot be rated; Guardrail is still under construction.

[C 2] – Embankment (Apply to Upstream & Downstream Slopes Separately)

According to ODOT Culvert Inspection Manual (2003; Draft) – Modified slightly.

Rating	Descriptions
9 (Excellent)	No noteworthy conditions detected on embankment slopes within 100' of culvert.
8 (Very Good)	Minor erosion in one area away from the culvert; Vegetation intact.
7 (Good)	Minor erosion in isolated areas (bare soil exposed slightly) away from the structure, No threats to the culvert and headwall.
6 (Satisfactory)	Moderate erosion in one area away from the structure; Soils exposed in the area; No threats to the culvert and headwall.
5 (Fair)	Moderate erosion in isolated areas, mostly away from the structure; Soils exposed & guardrail impacted in the area; Minor erosion behind the headwall; No cracks on the headwall.
4 (Poor)	Erosion impacting guardrail performance; Moderate erosion behind the headwall; Slope stability problem found in isolated areas; Minor hairline cracks on the headwall; Slight movement of the headwall.
3 (Serious)	Slope stability problem at isolated locations (eroding way the shoulder section of the roadway); Severe erosion behind the headwall; It has caused extensive hairline cracks and/or a moderate movement (ex. tilting) on the headwall.
2 (Critical)	Severe erosion taking place, causing damage to the roadway shoulder section; headwall has physical damages (ex. severe cracks) and tilted significantly.
1 (Imminent Failure)	One lane of traffic is closed due to embankment failure; Several guardrail posts are hanging in the air due to major erosion and/or slope stability problem.
0 (Failed)	Embankment has collapsed (can lead to the loss of culvert).
- 1	Cannot be rated; Embankment is still under construction.

Secondary Data

[C 3] – Headwall/Wingwall (Apply to Inlet & Outlet Separately)

Rating	Descriptions for:		
	Cracking	**Deterioration (Spalling, Delamination, …)**	**Movement (Settlement, Rotation, …)**
9 (Excellent)	New condition.	New condition.	New condition.
8 (Very Good)	Aged concrete; Some discolorations; No cracks.	No signs of material deterioration. Minor discoloration.	No movement.
7 (Good)	A few to several hairline cracks detected.	Light scaling (less than 1/8 in deep); Slight loss of mortar. Aggregates not exposed.	Slight movement on one side (or in one area).
6 (Satisfactory)	Extensive hairline cracking. No rebars exposed.	Minor delamination or spalling along cracks. Surface scaling 1/8 to 1/4 in deep. Some small aggregates lost.	Slight movement on both sides.
5 (Fair)	One of the cracks is at least 0.1 inch wide.	Moderate delamination, Moderate spalling. Rebars beginning to surface.	Moderate movement on one side (or in one area).
4 (Poor)	A few major cracks in addition to some hairline cracks.	Moderate spalling/scaling at isolated locations. One side of the first layer of rebars exposed .	Moderate movement on both sides.
3 (Serious)	Several major cracks running through the wall.	Moderate scaling has occurred at many locations. First layer of rebars exposed completely. Moderate degree of concrete softening.	Severe movement on one side (or in one area). Rotation up to 4" per foot.
2 (Critical)	Numerous major cracks. Some regions are becoming almost loose.	Severe spalling/scaling has occurred extensively.	Severe movement on both sides.
1 (Critical)	Major portion of the headwall gone; Rebars exposed extensively and corroded severely.		Headwall has partially failed.
0 (Failure)	Headwall has collapsed completely.		

Secondary Data

[C 4.a] – Channel (General)

According to ODOT Culvert Inspection Manual (Draft 2003) – Modified Slightly.

Rating	Descriptions for:		
	Alignment	**Scouring**	**Obstruction**
9 (Excellent)	New conditions. Channel is straight for more than 100' at both upstream & downstream. No adverse conditions detected.	New conditions. No scouring at either inlet or outlet ends.	New conditions. No debris or sediment accumulation anywhere.
8 (Very Good)	Channel straight for 50' to 100' at one end, for more than 100' at other end.	Very minor (< 6" deep) scouring at both inlet and outlet ends.	Minor debris accumulation.
7 (Good)	Channel is straight for 50' to 100' at both ends; Minor sediment accumulation; Bush growing.	Minor (6" to 12" deep) scouring at one end.	Minor sedimentation and debris accumulation; Up to 5% blockage of channel opening.
6 (Satisfactory)	Channel is straight for 20' to 50' at one end; Channel is curved by 20˚ to 40˚ angle near inlet; Deposit causing channel to split.	Minor (6" to 12" deep) scouring at both ends; Top of footings is exposed.	Minor sedimentation and debris. Up to 10% blockage of channel opening; Bush or tree growing in channel.
5 (Fair)	Channel is straight for 20' to 50' at both ends; Channel curved by 40˚ to 50˚ angle near inlet; Flow hitting outside headwall; Stream meandered; Signs of Bank erosion.	Minor (6" to 12" deep) scouring at one end; Moderate (12" to 24" deep) scouring at the other end; Footings along the side are exposed.	Waterway moderately (up to 25%) restricted by tree, shrubs, or sedimentation; Bush or tree growing in channel.
4 (Poor)	Channel curved by 50˚ to 70˚ angle near inlet; Flow enters culvert by other means than design opening; Signs of Bank erosion.	Severe (2' to 3' deep) scouring at one end; Less scouring at the other end; Bottom of footings is exposed; Not undermining cutoff walls/headwalls.	Partial (up to 50%) blockage of channel opening; Large debris in the waterway; Occasional overtopping of roadway.
3 (Serious)	Channel curved by 70˚ to 90˚ turn near inlet; Erosion behind wingwalls; Erosion of embankment encroaching on roadway.	Major (> 3' deep) scouring at one end; Cutoff walls and/or headwalls being undermined; Footings are undermined; Structure has been displaced or settled.	Mass drift accumulation has restricted 75% of channel opening; Occasional overtopping of roadway.
2 (Critical)	Channel flow piping around culvert; Erosion of embankment encroaching on roadway.	Structure or roadway weakened by bank erosion or scour problem; danger of collapse sometime in the future.	Culvert waterway blocked up to 85% by mass drift accumulation; Frequent overtopping of roadway w/ significant traffic delays.
1 (Failure Imminent)	No channel flow enters culvert; Severe piping problem around culvert; Road may be closed due to channel failure.	Structure or approach weakened; danger of immediate collapse.	Culvert waterway 100% blocked by deposits; Water pooling outside and not flowing through pipe; Road may be closed.
0 (Failed)	Pipe has collapsed.	Pipe has collapsed.	Pipe has collapsed.
- 1 (Under Construction)	Cannot be rated; still under construction.		

[C 4.b] Channel (Protection)

According to ODOT Culvert Inspection Manual (2003; Draft)

Rating	Descriptions
9 (Excellent)	Channel protections are not required or are in a stable condition.
8 (Very Good)	No noteworthy deficiencies that affect the channel protection; Banks are protected or well vegetated.
7 (Good)	Channel bank is beginning to slump; Embankment protection has minor damage; Bank protection is in need of minor repairs.
6 (Satisfactory)	Riprap starting to wash away; Cracked concrete channel protection.
5 (Fair)	Broken up concrete channel protection at inlet; Bank protection has eroded.
4 (Poor)	Channel protection is severely undermined; Stone is completely washed away; Major erosion; Failed concrete channel protection; Bank or embankment protection is severely undermined.
3 (Serious)	Channel protection has failed; Channel has moved to where the culvert and approach roadway are threatened.
2 (Critical)	Channel protection has failed; Channel flow is causing major scour effects.
1 (Imminent Failure)	Culvert closed because of channel failure.
0 (Failed)	Culvert has collapsed completely.

[C6] Sediment Inside Culvert

Rating	Descriptions
9 (Excellent)	New condition; No sediment accumulation at all.
8 (Very Good)	Less than 0.5 in. deep sediment accumulation inside the culvert; Sediment has no impact on drainage flow.
7 (Good)	0.5 to 2 in. deep sediment accumulation inside the culvert; or Up to 5% of the culvert opening is filled with sediment ; Sediment has little impact on drainage flow.
6 (Satisfactory)	2 to 4 in. deep sediment accumulation inside the culvert; or Up to 10% of the culvert opening is filled with sediment
5 (Fair)	4 to 6 in. deep sediment accumulation inside the culvert; or Up to 25% of the culvert opening is filled with sediment
4 (Poor)	Sediment accumulation up to 12 in. in some areas inside the culvert; or Up to 35% of the culvert opening is filled with sediment Sedimentation begins to affect the drainage flow through the culvert.
3 (Serious)	Sediment accumulation up to 24 in. in some areas inside the culvert; or Up to 50% of the culvert opening is filled with sediment
2 (Critical)	Sediment accumulation up to 36 in. in some areas inside the culvert; or Up to 65% of the culvert opening is filled with sediment
1 (Imminent Failure)	Sediment accumulation is more than 36 in. inside the culvert; Up to 80% of the culvert opening is filled with sediment; Hydraulic function of the original culvert has been severely diminished.
0 (Not Functioning)	The culvert is silted up with sediment all the way. The culvert is not functioning as a drainage structure.

Detailed Dimensional Measurements Taken Inside Metal Culvert

Date: ________________, _________

By: ____

Method Used: ____

Metal Culvert No.: _______

ODOT District No.: _______

County: ________________

Route: ________________

Location (SLM, …): _________________________________

Culvert Type: _________________________________

Location			
Rise (R)			
Span (S)			
Left Span (LS)			
Right Span (RS)			
Top Mid-Ordinate (TMO)			
Top Left Chord (TLC)			
Top Right Chord (TRC)			
Top Left Mid-Ordinate (TLMO)			
Top Right Mid-Ordinate (TRMO)			

Location			
Rise (R)			
Span (S)			
Left Span (LS)			
Right Span (RS)			
Top Mid-Ordinate (TMO)			
Top Left Chord (TLC)			
Top Right Chord (TRC)			
Top Left Mid-Ordinate (TLMO)			
Top Right Mid-Ordinate (TRMO)			

APPENDIX D:
Proposed Culvert Rating System (Thermoplastic Pipe Culverts)

PLASTIC PIPE INSPECTION DATA SHEET

Project Culvert No. _____ : Plastic Pipe No. _____

Inspection Time/Date		
Inspector Names	**(ORITE)**	**(JHA)**

A. Background Information

1	**ODOT District No.**		
2	**County** (Enter code)		Code =
3	**Route**		
4	**Pipe Location** (S.L.M.; GPS; Sta.)		
5	**Functional Classif.**		Code =
6	**ADT** (Year)		
7	**Pipe Type** (enter code; mention pipe material)		Code = (Shape) Code = (Material)
8	**Pipe Size (Diameter)**		
9	**No. of Cells**		
10	**Pipe Length**	No. of Sections =	
11	**Pipe Slope (ft/ft) and/or Invert Elevs.**		
12	**Corrugation Size**	**Pitch:** **Wall Thickness =**	**Depth:**
13	**Joint Coupler Type**		
14	**Installation Year**		
15	**Year Modified**		
16	**Extension @ Inlet**	**Shape:**	**Material:**
		Size:	**Wall Thickness:**
		Year:	**Length:**
	Extension @ Outlet	**Shape:**	**Material:**
		Size:	**Wall Thickness:**
		Year:	**Length:**
17	**Max. Height of Cover**		
18	**Headwall Type** (Enter code as well)	**@ Inlet:**	Code =
		@ Outlet:	Code =
19	**Hydraulic Capacity & Pipe Full Velocity (ft/s)***	**Hydraulic Capacity =** **Flow Velocity (fps) =** **Abrasive (Y/N)?:**	
20	**Past Inspection Notes & Additional Data**		

[Note] * Based on the Manning formula.

B. Primary Data Collected @ Station ____________________

Describe below the station location with respect to the plastic pipe structure:

ODOT District No.		
County		Code =
Route		
Plastic Pipe Description		Code =
Time/Date of Inspection		

1	**Rise (Vert. Diameter) Dimension**		
2	**Span (Horiz. Diameter) Dimension**		
3	**Shape Observations** (Enter rating & notes for each item)		**Deflection:**
			Distortion:
4	**Pipe Wall Surface in <u>Crown</u> Region** (Enter rating & notes for each item)		**Cracking:**
			Buckling:
5	**Pipe Wall Surface in <u>Shoulder</u> Region** (Enter rating & notes for each item)		**Cracking:**
			Buckling:
6	**Pipe Wall Surface in <u>Springline</u> Region** (Enter rating & notes for each item)		**Cracking:**
			Buckling:
7	**Pipe Wall Surface in <u>Haunch</u> Region** (Enter rating & notes for each item)		**Cracking:**
			Buckling:
8	**Pipe Wall Surface in <u>Invert</u> Region** (Enter rating & notes for each item)		**Buckling:**
			Buckling:
9	**Joints** (Enter rating & notes for each item)		**Opening:**
			Cracks:

[Note] Use multiple copies of this page for recording primary inspection data at additional stations established along the plastic pipe structure. Refer to the attached rating criteria for plastic pipes.

B. Primary Data Collected – Continued

ODOT District No.		
County		Code =
Route		
Plastic Pipe Description		Code =
Time/Date of Inspection		

10	**Inlet Condition** (Enter rating & notes)		
11	**Outlet Condition** (Enter rating & notes)		
12	**Slope & Settlement (including sagging)** (Enter rating & notes)		
13	**Horiz. Alignment** (Enter rating & notes)		
14	**Additional Data**		

C. Secondary Data Collected

ODOT District No.		
County		Code =
Route		
Plastic Pipe Description		Code =
Time/Date of Inspection		

1	**Roadway** (Enter rating & notes)		**Roadway Surface:**
			Guardrail:
2	**Embankment** (Enter rating & notes for each side slope)		**Upstream:**
			Downstream:
3.a	**Headwall @ Inlet** (Enter rating & notes for each category)		**Cracking:**
			Deterioration:
			Movement:
3.b	**Headwall @ Outlet** (Enter rating & notes for each category)		**Cracking:**
			Deterioration:
			Movement:
4	**Channel** (Enter rating & notes for each of the three factors listed)		**Alignment:**
			Scour:
			Obstruction:
			Protection:
5	**Drainage Flow**	**pH**	
		Temp.	˚C
		DO	% of Saturated DO
		Flow Velocity	; **(Abrasive – y/n?)**
6	**Sediment Inside Pipe:** *** Rating = [ ]**	**Description**	
		Max. Aggr. Size	
		Depth	
7	**Backfill Soil**	**Any Relevant Data:**	
8	**Pipe Wall**	**Coupon Samples**	

C. Secondary Data Collected

ODOT District No.		
County		Code =
Route		
Plastic Pipe Description		Code =
Time/Date of Inspection		

9	**Additional Data** ex. Wingwalls (if any)	

D. Photographs Taken

Type of Camera Used	
Photographer's Name	
No. of Pictures Taken	
Management of Pictures Taken	

E. Level of Inspection

Components	Inlet Section	Outlet Section	Main Barrel
Level of Inspection: Specify --- X = Inspection from ends (no entry) M = Manned entry inspection V = Video inspection			
Type of Video Equipment Used			
Additional Comments			

F. Field Sketches

ODOT District No.		
County		Code =
Route		
Plastic Pipe Description		Code =
Time/Date of Inspection		

Draw sketches in the space below to describe conditions encountered in the field (if necessary):

Dimensional Measurements Taken Inside Plastic Pipe

Date: ____________________, ____________

By: ____

Plastic Pipe No.: ________

ODOT District No.: ________

County: _________________

Route: _________________

Location (SLM, …): ___________________________________

Pipe Type: ___________________________________

Method of Measurements: _____________________________________

Item	Data:
Location of Cross-Section	
Rise or Vertical Diameter (R)	
Span or Horizontal Diameter (S)	
Additional Measurements or Notes	

Item	Data:
Location of Cross-Section	
Rise or Vertical Diameter (R)	
Span or Horizontal Diameter (S)	
Additional Measurements or Notes	

Item	Data:
Location of Cross-Section	
Rise or Vertical Diameter (R)	
Span or Horizontal Diameter (S)	
Additional Measurements or Notes	

Primary Data

[B 3] – Shape

Rating	Category	Conditions
9 (Excellent)	Deflection	Less than 1% over the design value.
	Distortion	Circular, symmetric shape; No flattening, no bulging.
8 (Very Good)	Deflection	Between 1% and 2% over the design value.
	Distortion	Slightly oval shape, Symmetric; Almost no flattening; No bulging.
7 (Good)	Deflection	Between 2% and 2.5% over the design value.
	Distortion	Slightly oval shape, Symmetric; Minor flattening; No bulging.
6 (Fair)	Deflection	Between 2.5% and 3% over the design value.
	Distortion	Oval shape, symmetric; Minor flattening and/or Minor bulging.
5 (Fair-Marginal)	Deflection	Between 3% and 3.5% over the design value.
	Distortion	Slightly non-symmetric; Moderate flattening and/or Moderate bulging.
4 (Marginal)	Deflection	Between 3.5% and 4% over the design value.
	Distortion	Moderately non-symmetric; Severe flattening and/or Severe bulging.
3 (Poor)	Deflection	Between 4% and 5% over the design value.
	Distortion	Significant distortion; Severe flattening and/or Severe bulging.
2 (Very Poor)	Deflection	More than 5% over the design value; Pipe has not collapsed yet.
1 (Failure)	Deflection	More than 10% over the design value; Pipe has not collapsed yet.
0 (Failure)		Pipe has collapsed completely.

[Note] Deflection = Vertical Deflection = (Reduction in Vertical Inside Diameter) divided by (Design Vertical Inside Diameter).

[B 4 through B 8] – Pipe Wall Surface

Rating	Category	Conditions
9 (Excellent)	Cracking	No cracking, no discoloration.
	Buckling	Smooth wall, No signs of wall buckling.
8 (Very Good)	Cracking	No cracking, Minor discoloration at isolated locations.
	Buckling	---
7 (Good)	Cracking	Minor hairline cracking at one or two isolated locations; No opening at seams.
	Buckling	Relatively smooth wall; Signs of minor wall buckling.
6 (Fair)	Cracking	Minor hairline cracking at more than a few isolated locations; No opening at seams.
	Buckling	Minor dimpling appearing at isolated small area (less than 1/16 of circumference or 11.25˚ arc area); Dimples less than 0.25 in. deep.
5 (Fair-Marginal)	Cracking	Minor hairline cracking at more than a few isolated locations; Minor opening at isolated seams.
	Buckling	Minor dimpling appearing over 1/16 to 1/8 of circumference or 11.25˚ to 22.5˚ arc area); Dimples less than 0.25 in. deep.
4 (Marginal)	Cracking	Extensive hairline cracking. Minor opening at isolated seams.
	Buckling	Moderate degree of dimpling appearing; Dimples between 0.25 and 0.5 in. deep.
3 (Poor)	Cracking	Cracks extensive, some cracks opening greater than 0.1 in.; Opening at seams. No signs of backfill infiltration and/or exfiltration.
	Buckling	Moderate degree of dimpling appearing; Dimples more than 0.5 in. deep. No wall tearing/cracking yet in the buckled region.

Primary Data

[B 4 through B 8] – Pipe Wall Surface

Rating	Category	Conditions
2 (Critical)	Cracking	Cracks extensive, some cracks opening greater than 0.1 in. ; Opening at seams. Signs of backfill infiltration and/or exfiltration.
	Buckling	Severe dimpling accompanied with wall tearing/cracking; Backfill is not exposed in the bucked region (i.e., outer wall is still intact).
1 (Failure)		Pipe has collapsed partially.
0 (Failure)		Total failure of pipe and fill.

[B 9] – Joints

Rating	Category	Conditions
9 (Excellent)	Opening	Tight with no apparent defects.
	Cracking	New condition.
8 (Very Good)	Opening	Minor opening, no signs of backfill infiltration and/or exfiltration.
	Cracking	No cracking. Condition like new.
7 (Good)	Opening	Minor opening, signs of possible backfill infiltration and/or exfiltration.
	Cracking	Minor hairline cracking at one isolated location.
6 (Fair)	Opening	Slight opening, minor backfill infiltration
	Cracking	Minor hairline cracking at a few isolated locations.
5 (Fair-Marginal)	Opening	Moderate joint opening, minor backfill infiltration and/or exfiltration.
	Cracking	Extensive hairline cracking.
4 (Marginal)	Opening	---
	Cracking	Cracks extensive and opening greater than 0.1 in.
3 (Poor)	Opening	Moderate backfill infiltration and/or exfiltration due to joint opening. No exposed fill material yet.
	Cracking	Cracks extensive and opening greater than 0.1 in. Signs of minor backfill infiltration and/or exfiltration.
2 (Critical)	Opening	Separation of joints, exposed fill material, severe backfill infiltration and/or exfiltration.
	Cracking	Cracks extensive and opening greater than 0.1 in. Signs of significant backfill infiltration and/or exfiltration.
1 (Failure)		Pipe has partially collapsed.
0 (Failure)		Total failure of pipe and fill.

[B 10 & 11] – Inlet & Outlet Conditions

Rating	Condition
9 (Excellent)	New Condition.
8 (Very Good)	Good, no signs of UV deteriorations, no movement (dropping off or lifting up) of the pipe end, no scouring.
7 (Good)	No signs of pipe material deterioration, minor physical damages (scratches, tearing, …) to the pipe end; no movement of the pipe end section; no scouring.
6 (Fair)	No signs of pipe material deterioration, minor physical damages (scratches, tearing, …) of the pipe end, minor movement (dropping off or lifting up) of the pipe end section; or minor scouring at the end.
5 (Fair-Marginal)	Minor deterioration of pipe material, minor physical damages (scratches, tearing, …) of the pipe end, minor movement (dropping off or lifting up) of the pipe end, or minor scouring at the end.

Rating Criteria for Plastic Pipes (cont'd)

Primary Data

[B 10 & 11] – Inlet & Outlet Conditions

Rating	Condition
4 (Marginal)	Minor UV deterioration of the pipe material, moderate movement of the pipe end, or moderate scouring.
3 (Poor)	N/A
2 (Very Poor)	Significant UV degradation of the pipe material, severe physical damages (large deformations, cracking, tearing, …) to the pipe end section; severe movement of the end, or severe scouring at the end.
1 (Failure)	Pipe and fill partially collapsed.
0 (Failure)	Total failure of pipe and fill.

[B 12] – Slope & Settlement

Rating	Descriptions
9 (Excellent)	Good; uniform slope; no settlement.
8 (Very Good)	Minor settlement at one location.
7 (Good)	Minor settlement at isolated locations.
6 (Fair)	Minor settlement at numerous locations along the culvert.
5 (Fair-Marginal)	Moderate settlement at one location.
4 (Marginal)	Moderate settlement of the culvert; some ponding of water due to sagging; upstream end can be seen from the downstream end.
3 (Poor)	Severe settlement in one section.
2 (Very Poor)	Pipe is not functioning due to sever settlement problem; upstream end cannot be seen from the downstream end; ponding of water more than 50% of the pipe length.
1 (Critical)	Pipe has partially collapsed.
0 (Failure)	Pipe has collapsed completely.

[B 13] – Horizontal Alignment

Rating	Descriptions
9 (Excellent)	New condition.
8 (Very Good)	Good: no horizontal misalignment.
7 (Good)	Generally good; minor misalignment at one location; no backfill infiltration problem exists yet.
6 (Fair)	Generally fair; minor misalignment at isolated locations; no backfill infiltration problem exists yet.
5 (Fair-Marginal)	Moderate misalignment at one location; minor backfill infiltration may be possible there.
4 (Marginal)	Moderate misalignment at isolated locations; minor backfill infiltration may be possible.
3 (Poor)	Significant misalignment of the culvert at isolated locations; minor backfill infiltration is observed.
2 (Very Poor)	Pipe is not functioning due to severe alignment problems throughout; signs of backfill infiltration seen at more than a few locations.
1 (Critical)	Pipe has failed partially.
0 (Failure)	Pipe has collapsed completely.

Rating Criteria for Plastic Pipes (cont'd)

Secondary Data

[C 1.a] – Roadway Surface

According to ODOT Culvert Inspection Manual (2003; Draft) – Modified somewhat.

Rating	Descriptions
9 (Excellent)	New condition; no defects noticed.
8 (Very good)	Minor hairline cracks; No dip (settlement).
7 (Good)	Minor hairline cracks; Minor scaling; Very small potholes; No dip (settlement).
6 (Satisfactory)	Minor potholes; Minor dip (settlement); cracking with width less than 0.1 in; Transverse cracks do not extend all the way across the roadway.
5 (Fair)	Moderate size potholes; Minor spalling; Minor dip accompanied with a few cracks; Transverse cracks are wider than 0.1 in and extend all the way across the roadway.
4 (Poor)	Moderate dip in roadway; Numerous cracks on the surface layer (starting to break up the pavement).
3 (Serious)	Significant dip; extensive cracking of roadway surface (breaking up the pavement); Repairs required immediately.
2 (Critical)	Significant dip; extensive cracking of roadway surface, damages on the pavement surface layer, posing potential danger to drivers; Embankment washed out next to pavement.
1 (Closed)	Road closed; Impending pavement and/or embankment failure.
0 (Failed)	Roadway is closed to traffic; Embankment and/or pavement failed.
- 1	Cannot be rated; Roadway is still under construction.

[C 1.b] – Guardrail

According to ODOT Culvert Inspection Manual (2003; Draft)

Rating	Descriptions
9 (Excellent)	New condition; Guardrail free from any defects.
8 (Very good)	Minor discoloration; No noteworthy deficiencies noted;
7 (Good)	Minor deficiencies noted within 100' of culvert; No bolts missing; Misalignment of 1 or 2 guardrail posts.
6 (Satisfactory)	Minor collision damage; Up to 10% loss of section of posts due to decay; Guardrail position is noticeably higher or lower than the standard 27"; Guardrail panels are rusted; Several bolts are missing; Misalignment of up to 3 guardrail posts.
5 (Fair)	Moderate collision damage; Up to 20% loss of section of posts due to decay; Guardrail position is noticeably higher or lower than the standard 27"; Guardrail panels are rusted; Several bolts are missing; Misalignment of up to 5 guardrail posts.
4 (Poor)	Major collision damage; Up to 30% loss of section of posts due to decay; Guardrail position is noticeably higher or lower than the standard 27"; Guardrail panels are rusted; Several bolts are missing; Misalignment of up to 6 guardrail posts.
3 (Serious)	Major collision damage; Up to 50% loss of section of posts due to decay; Guardrail position is noticeably higher or lower than the standard 27"; Guardrail panels are rusted; Several bolts are missing; Misalignment of more than 6 guardrail posts.
2 (Critical)	Guardrail is not functioning; Up to 90% of decay of posts.
1 (Closed)	Guardrail has collapsed partially.
0 (Failed)	Guardrail has collapsed completely.
- 1	Cannot be rated; Guardrail is still under construction.

Secondary Data

[C 2] – Embankment (Apply to Upstream & Downstream Slopes Separately)

According to ODOT Culvert Inspection Manual (2003; Draft) – Modified slightly.

Rating	Descriptions
9 (Excellent)	No noteworthy conditions detected on embankment slopes within 100' of culvert.
8 (Very Good)	Minor erosion in one area away from the culvert; Vegetation intact.
7 (Good)	Minor erosion in isolated areas (bare soil exposed slightly) away from the structure, No threats to the culvert and headwall.
6 (Satisfactory)	Moderate erosion in one area away from the structure; Soils exposed in the area; No threats to the culvert and headwall.
5 (Fair)	Moderate erosion in isolated areas, mostly away from the structure; Soils exposed & guardrail impacted in the area; Minor erosion behind the headwall; No cracks on the headwall.
4 (Poor)	Erosion impacting guardrail performance; Moderate erosion behind the headwall; Slope stability problem found in isolated areas; Minor hairline cracks on the head-wall; Slight movement of the headwall.
3 (Serious)	Slope stability problem at isolated locations (eroding away the shoulder section of the roadway); Severe erosion behind the headwall; It has caused extensive hairline cracks and/or a moderate movement (ex. tilting) on the headwall.
2 (Critical)	Severe erosion or slope movement taking place, causing damage to the roadway shoulder section; headwall has physical damages (ex. severe cracks) and tilted significantly.
1 (Imminent Failure)	One lane of traffic is closed due to embankment failure; Several guardrail posts are hanging in the air due to major erosion and/or slope stability problem.
0 (Failed)	Embankment has collapsed (can lead to the loss of culvert).
- 1	Cannot be rated; Embankment is still under construction.

Secondary Data

[C 3] – Headwall/Wingwall (Apply to Inlet & Outlet Separately)

Rating	Descriptions for:		
	Cracking	**Deterioration (Spalling, Delamination, …)**	**Movement (Settlement, Rotation, …)**
9 (Excellent)	New condition.	New condition.	New condition.
8 (Very Good)	Concrete aged, some discolorations, No cracks.	No signs of material deterioration. Minor discoloration.	No movement.
7 (Good)	A few to several hairline cracks detected.	Light scaling (less than 1/8 in deep); Slight loss of mortar. Aggregates not exposed.	Slight movement on one side (or in one area).
6 (Satisfactory)	Extensive hairline cracking. No rebars exposed.	Minor delamination or spalling along cracks. Surface scaling 1/8 to 1/4 in deep. Some small aggregates lost.	Slight movement on both sides.
5 (Fair)	One of the cracks is at least 0.1 inch wide.	Moderate delamination, Moderate spalling. Rebars beginning to surface.	Moderate movement on one side (or in one area).
4 (Poor)	A few major cracks in addition to some hairline cracks.	Moderate spalling/scaling at isolated locations. One side of the first layer of rebars exposed .	Moderate movement on both sides.
3 (Serious)	Several major cracks running through the wall.	Moderate scaling has occurred at many locations. First layer of rebars exposed completely. Moderate degree of concrete softening.	Severe movement on one side (or in one area). Rotation up to 4" per foot.
2 (Critical)	Numerous major cracks. Some regions are becoming almost loose.	Severe spalling/scaling has occurred extensively.	Severe movement on both sides.
1 (Critical)	Major portion of the headwall gone; Rebars exposed extensively and corroded severely.		Headwall has partially failed.
0 (Failure)	Headwall has collapsed completely.		

Secondary Data

[C 4.a] – Channel (General)

According to ODOT Culvert Inspection Manual (Draft 2003) – Modified Slightly.

Rating	Descriptions for:		
	Alignment	**Scouring**	**Obstruction**
9 (Excellent)	New conditions. Channel is straight for more than 100' at both upstream & downstream. No adverse conditions detected.	New conditions. No scouring at either inlet or outlet ends.	New conditions. No debris or sediment accumulation anywhere.
8 (Very Good)	Channel straight for 50' to 100' at one end, for more than 100' at other end.	Very minor (< 6" deep) scouring at both inlet and outlet ends.	Minor debris accumulation.
7 (Good)	Channel is straight for 50' to 100' at both ends; Minor sediment accumulation; Bush growing.	Minor (6" to 12" deep) scouring at one end.	Minor sedimentation and debris accumulation; Up to 5% blockage of channel opening.
6 (Satisfactory)	Channel is straight for 20' to 50' at one end; Channel is curved by 20˚ to 40˚ angle near inlet; Deposit causing channel to split.	Minor (6" to 12" deep) scouring at both ends; Top of footings is exposed.	Minor sedimentation and debris. Up to 10% blockage of channel opening; Bush or tree growing in channel.
5 (Fair)	Channel is straight for 20' to 50' at both ends; Channel curved by 40˚ to 50˚ angle near inlet; Flow hitting outside headwall; Stream meandered; Signs of Bank erosion.	Minor (6" to 12" deep) scouring at one end; Moderate (12" to 24" deep) scouring at the other end; Footings along the side are exposed.	Waterway moderately (up to 25%) restricted by tree, shrubs, or sedimentation; Bush or tree growing in channel.
4 (Poor)	Channel curved by 50˚ to 70˚ angle near inlet; Flow enters culvert by other means than design opening; Signs of Bank erosion.	Severe (2' to 3' deep) scouring at one end; Less scouring at the other end; Bottom of footings is exposed; Not undermining cutoff walls/headwalls.	Partial (up to 50%) blockage of channel opening; Large debris in the waterway; Occasional overtopping of roadway.
3 (Serious)	Channel curved by 70˚ to 90˚ turn near inlet; Erosion behind wingwalls; Erosion of embankment encroaching on roadway.	Major (> 3' deep) scouring at one end; Cutoff walls and/or headwalls being undermined; Footings are undermined; Structure has been displaced or settled.	Mass drift accumulation has restricted 75% of channel opening; Occasional overtopping of roadway.
2 (Critical)	Channel flow piping around culvert; Erosion of embankment encroaching on roadway.	Structure or roadway weakened by bank erosion or scour problem; danger of collapse sometime in the future.	Culvert waterway blocked up to 85% by mass drift accumulation; Frequent overtopping of roadway w/ significant traffic delays.
1 (Failure Imminent)	No channel flow enters culvert; Severe piping problem around culvert; Road may be closed due to channel failure.	Structure or approach weakened; danger of immediate collapse.	Culvert waterway 100% blocked by deposits; Water pooling outside and not flowing through pipe; Road may be closed.
0 (Failed)	Pipe has collapsed.	Pipe has collapsed.	Pipe has collapsed.
- 1 (Under Construction)	Cannot be rated; still under construction.		

[C 4.b] Channel (Protection)

According to ODOT Culvert Inspection Manual (2003; Draft)

Rating	**Descriptions**
9 (Excellent)	Channel protections are not required or are in a stable condition.
8 (Very Good)	No noteworthy deficiencies that affect the channel protection; Banks are protected or well vegetated.
7 (Good)	Channel bank is beginning to slump; Embankment protection has minor damage; Bank protection is in need of minor repairs.
6 (Satisfactory)	Riprap starting to wash away; Cracked concrete channel protection.
5 (Fair)	Broken up concrete channel protection; Bank protection is eroded.
4 (Poor)	Channel protection is severely undermined; Stone is completely washed away; Major erosion; Failed concrete channel protection at inlet; Bank or embankment protection is severely undermined.
3 (Serious)	Channel protection has failed; Channel has moved to where the culvert and approach roadway are threatened.
2 (Critical)	Channel protection has failed; Channel flow is causing major scour effects.
1 (Imminent Failure)	Culvert closed because of channel failure.
0 (Failed)	Culvert has collapsed completely.

[C6] Sediment Inside Culvert

Rating	**Descriptions**
9 (Excellent)	New condition; No sediment accumulation at all.
8 (Very Good)	Less than 0.5 in. deep sediment accumulation inside the culvert; Sediment has no impact on drainage flow.
7 (Good)	0.5 to 2 in. deep sediment accumulation inside the culvert; or Up to 5% of the culvert opening is filled with sediment ; Sediment has little impact on drainage flow.
6 (Satisfactory)	2 to 4 in. deep sediment accumulation inside the culvert; or Up to 10% of the culvert opening is filled with sediment
5 (Fair)	4 to 6 in. deep sediment accumulation inside the culvert; or Up to 25% of the culvert opening is filled with sediment
4 (Poor)	Sediment accumulation up to 12 in. in some areas inside the culvert; or Up to 35% of the culvert opening is filled with sediment Sedimentation begins to affect the drainage flow through the culvert.
3 (Serious)	Sediment accumulation up to 24 in. in some areas inside the culvert; or Up to 50% of the culvert opening is filled with sediment
2 (Critical)	Sediment accumulation up to 36 in. in some areas inside the culvert; or Up to 65% of the culvert opening is filled with sediment
1 (Imminent Failure)	Sediment accumulation is more than 36 in. inside the culvert; Up to 80% of the culvert opening is filled with sediment; Hydraulic function of the original culvert has been severely diminished.
0 (Not Functioning)	The culvert is silted up with sediment all the way. The culvert is not functioning as a drainage structure.

APPENDIX E: Culvert Spreadsheet Data
(on CD-ROM Disk)

APPENDIX F: Culvert Photographs
(on CD-ROM Disk)

APPENDIX G:
Culvert Rehabilitation Techniques
Engineering Drawings and Specifications

Specifications were written based on review of manufacture and other government agency specifications along with data collected on the individual treatments. Likewise, sample plan sheets are a compilation of information from similar sources.

<u>Invert Replacement</u>

Considerations when using ODOT Specification 603.11:

ODOT currently has a specification that addresses field paving of a new or existing pipe. (CMS 603.11). This specification is best suited for inverts in good condition or new installations. Deteriorated inverts will require additional reinforcing. Reinforcing for deteriorated inverts should be designed to reintroduce structural integrity to the pipe. Other concerns should be addressed in notes or plan details. For example, the pipe should be cleaned prior to paving. This should include a definition of clean, such as this excerpt from Maryland's Category 400 Structures specification, "The surface of the structure should be free of all loose scale, concrete, or rust; oil, asphalt coatings, and any other foreign material that would prohibit grout from bonding to the surface of the structure. When placing the grout, the surface should be clean and dry."

Designer Notes:

ODOT's L&D Manual, Volume 2 requires concrete field paving on certain gauge metal structures for specified design life. District 11 has included cutoff walls to eliminate undermining of the field paving at the inlet end. They report better success using this technique. The plans should either reference the standard reinforcing outlined in the current specification or include a detail depicting the reinforcing mat.

Sample Plan Sheets:

On the sample detail sheet, Detail 'A', is a good example to include in invert replacement projects. It is from District 11. Detail 'B' shows another variation that has been used by the state of Maryland. Detail 'B' also includes a proposed detail to be used with circular pipes. A sample plan sheet from District 11, with their cutoff wall is included.

<u>Sliplining</u>

Proposed Changes to ODOT Supplemental Specification 837:

ODOT currently has a draft Supplemental Specification 837, Liner Pipe. It is a comprehensive specification, but ODOT may want to consider modifying the specification or including in plan notes the following:

- Add joints shall not decrease the hydraulic capacity of the liner.
- Clarify size selection based on material selection, since only one liner is shown in the plans, but the contractor can select other 'equal' hydraulic choices.
- Consider requiring ports for insuring complete backfill in larger or longer pipes. These can also act as pressure relief valves during the grouting process.
- Establish how to determine if all voids are filled. Will sounding the sides of the pipe, or using drill holes to test for voids do this?
- Require measurement of slope of pipe in sensitive slope conditions.
- Make reference in SS 837 to the appropriate specification for flowable grout and low strength mortar backfill.

- Clearer definition of cleaning the pipe. Specify how to determine the pipe is clean.
- Specify what is to be done if voids are encountered during the cleaning process. This is probably best handled as a plan note with contingency quantities.
- Require that the contractor verify ability to install the proposed liner prior to ordering pipe. This will eliminate the possibility of ODOT having to buy a pipe that was ordered based on the design survey data. The pipe may have changed shape from the time between the design survey and the contract sold date.
- Consider establishing guidelines for how far the liner can/cannot protrude from the end of pipe, or how the liner is to be cut.
- May want to include dewatering basin requirements.

Designer Notes:
Designers need to be aware that ODOT generally only shows one option on the plans, but other pipe materials are allowed. For instance, different pipe materials that are allowed may require different pipe sizes for hydraulic reasons. It may be helpful to include a table or listing in the plans of different sizes for different materials if appropriate. Designers should be aware of possible needs to include other pay items in a liner project, such as additional mortar, headwalls, riprap, rock channel protection, and seeding/mulching. If the designer is aware that the pipe is heavily silted or has other extreme conditions, such as dam control, or unusual flow patterns, they should include that information in the general notes, or reference an appropriate contact. Designers should be aware that different pipe material choices will create different velocities and the most extreme should be accounted for in designing the dissipaters, or eliminate that pipe material choice from the options if it is not an appropriate option.

Sample Plan Sheets:
The sample plan sheet shown is from District 5 and was observed under construction. District 5 has been doing slipliners for several years. In addition, on the sample details sheet, Detail 'C', is a good example of how to indicate placement of grout and lift tubes in the concrete bulkhead.

<u>CIPP (Cured in Place Pipe)</u>
Proposed Draft Specification:
One significant change to the current specifications used by ODOT is to not include the filling of voids as incidental to the CIPP. Designing the liner, cleaning the pipe and inspection is still incidental to the cost of the CIPP. The recommended draft specification is shown below.

Designer Notes:
Designer should make sure there is enough space for setting up necessary equipment and still maintain traffic in an acceptable manner. Also, the designer needs to consider if facilities are available to dispose of hot water that could contain styrene. Design should be based on fully deteriorated gravity pipe as per ASTM F-1216. Any filling of voids should be paid under a separate pay item.

Sample Plan Sheet:
The included sample plan sheet is from a project in District 11.

STATE OF OHIO
DEPARTMENT OF TRANSPORTATION

SUPPLEMENTAL SPECIFICATION 999
CURED IN PLACE PIPE

Date

999.01 Description. This work consists of relining an existing culvert structure with a resin impregnated felt tube liner of the type and size specified.

999.02 Materials. Materials supplied shall be accordance with the following specifications: ASTM D-5813, ASTM F-1216, ASTM F-1743. The liner shall be designed by the manufacture as relining a fully deteriorated gravity pipe. The supplier must be from the acceptable list of approved manufacturers, which can be obtained from the Office of Structural Engineering. The liner must provide a flow capacity equal to or greater than that of the host pipe prior to installation.

999.03 Construction Methods, General. Installation shall be per the manufacturer's recommendations, with special attention to the following details. The contractor shall provide a copy of the manufacturers installation recommendations to the engineer at the pre-construction meeting.

999.04 Delivery and Storage. If the resin is applied off site the resin-impregnated liner shall be kept in thermostatically controlled refrigeration. The liner should not be kept longer than 10 days in refrigeration without the approval of the engineer.

999.05 Site Preparation. The contractor is responsible for cleaning the host pipe prior to liner installation. This includes roots, rocks, silt buildup, and any loose damaged sections of pipe. The engineer must approve the cleaning prior to liner installation.

999.06 Installation. The installation of the liner should be as per the manufacturer's instructions. Care must be taken that the pipe lining remains free of dirt and debris prior to lining. Temperature during curing must be measured, both inside and outside the tube, to verify temperatures to assure conformance to the cure profile. The CIPP may be installed either using the inversion process as per ASTM F-1216, or the pulled in place method as per ASTM F-1743. The liner used must be designed for the type of installation used. Following the curing process, the heated water must be cooled and disposed of properly. Following the liner completion, the site must be returned to an acceptable condition as per Section 104.

999.07 Appearance and Acceptance. The acceptance of the installed CIPP is based upon an arms reach or CCTV visual inspection. If CCTV is required the contractor shall supply the equipment at the request of the engineer. The CIPP may reflect minor defects at joints or deteriorated areas in the host pipe. Minor wrinkles at bends and joints are acceptable. There should be no holes, splitting, or rupturing in the CIPP. There should be no wrinkles in straight pipe segments. The CIPP should be fully inflated and in tight contact with the host pipe.

999.08 Environmental Requirements. Prior to starting construction, the contractor shall supply to the engineer a plan describing how the hot and possibly styrene-contaminated water will be captured. The plan shall also include the location to be used for disposal.

999.09 Method of Measurement. The quantity shall be for the actual length after the ends are cut. Measurement shall be to the nearest foot (meter).

999.10 Basis of Payment. Payment shall be for completed and accepted quantities at the contract price as follows:

Item	**Unit**	**Description**
999	Foot	Conduit, Cured in Place Pipe, ______”, _________(shape)
999	Meter	Conduit, Cured in Place Pipe, ______mm, _______(shape)

PVC- Spiral Wound

Designer Notes:

This is a costly operation and rarely performed in Ohio. It is good for areas with limited right of way or workspace. There are two basic types -- 1) Machine Spiral Wound PVC (Expandable Liner); and 2) Spiral Wound PVC (Fixed Diameter).

CALTRANS Specification:

The following are the draft CALTRANS Specifications for both types:

MACHINE SPIRAL WOUND POLYVINYL CHLORIDE (PVC) PIPE LINER (EXPANDABLE DIAMETER)

Machine spiral wound polyvinyl chloride (PVC) pipe liner (expandable diameter) shall be furnished and installed in existing culverts at the locations shown on the plans and in conformance with the details shown on the plans and these special provisions. Machine spiral wound polyvinyl chloride (PVC) pipe liner (expandable diameter) shall be wound directly into the existing culvert from an access point and expanded radially against the existing pipe. See Table A for profile diameter ranges.

Machine spiral wound polyvinyl chloride (PVC) pipe liner (expandable diameter) shall be manufactured from polyvinyl chloride (PVC) compounds and shall conform to the materials requirements for ribbed polyvinyl chloride (PVC) pipe in Section 64-1.02, "Materials" of the Standard Specifications. The profile type or initial stiffness factor shall be indicated on the plans or in the specifications.

Continuous, one part, PVC ribbed profile strips with "T" shaped ribs on the outside and smooth inner wall for all culvert diameters shall be used. Interlocking edges shall be used. The edges shall be locked together as the strip is wound into the pipe.

The initial stiffness factor of the ribbed profile strips used to form the liner pipe shall conform to Table A.

Table A

Profile Type	Diameter Range mm	Initial Stiffness Factor, E[1] $MPa\text{-}mm^3$
1	200 - 375	54.0×10^3
2	350 - 750	195.0×10^3

1. Stiffness factors shall be determined in accordance with ASTM Designation D-790 as modified in ASTM Designation F-1697.

The minimum width, height and wall thickness of the ribbed profile strips shall conform to Table B.

Table B

Profile Type	Minimum Width	Minimum Height	Minimum Wall Thickness
	mm	mm	mm
1	80.0	8.0	1.6
2	121.0	13.0	2.1

1. Physical dimensions shall be determined in accordance with ASTM Designation D-2122.

Material fabrication characteristics shall comply with ASTM Designation: F-1697.

A Certificate of Compliance shall be furnished to the Engineer in conformance with the provisions in Section 6-1.07, "Certificates of Compliance," of the Standard Specifications for each type of plastic pipe liner furnished. The certificate shall also include the manufacturer, plant, date of manufacture and shift, cell classification, unit mass, average pipe liner stiffness and profile type.

Each PVC continuous strip shall be distinctively marked on its inside surface at intervals not to exceed 1.5 m with a coded number which identifies the manufacturer, minimum strip thickness, profile type, size, plant, date of manufacture and shift, cell classification and profile type. This information shall be visible from inside the completed liner and also appear on each reel.

Include the paragraph below if there will be a need to divert flow from the stream or storm drain during the course of the work. For very minor flows, leave as is and allow Contractor to develop a plan and include it in this item of work. For significant flows or in environmentally sensitive locations, develop a separate item for Temporary Flow Diversion and show details of how it should be accomplished. If there will be no flows during construction, delete the paragraph below.

The Contractor shall provide for the control and diversion of flows in host pipes being rehabilitated. The bypass system shall be of adequate capacity and size to handle the flow. Prior to beginning any flow diversion work, the Contractor shall submit a plan showing the intended work, any calculations supporting the sizing of the system and a schedule indicating the duration of the flow diversion to the Engineer for approval.

The existing culvert shall be thoroughly cleaned of any obstacles prior to inserting the machine spiral wound polyvinyl chloride (PVC) pipe liner (expandable diameter). Earthy material, trash, cuttings, and other waste materials removed from the existing culverts shall be disposed of in conformance with the provisions in Section 7-1.13, "Disposal of Material Outside the Highway Right of Way," of the Standard Specifications.

The existing culvert shall be inspected using a closed circuit television (CCTV) camera, and the inspection recorded on videotape as specified in these special provisions, and as directed by the Engineer. During this phase of operation all service openings shall be precisely located longitudinally and radially, and logged for subsequent reconnection after the insertion of the liner pipe.

Prior to beginning any pipe lining work, cleaning and inspecting all existing pipe shall be performed as specified elsewhere in these special provisions.

After inspection of the existing pipe, the Contractor shall develop a written proposal describing the planned operations to repair the pipe. At a minimum, the proposal shall describe conditions found that may prevent proper installation of pipe liner (such as any sharp or protruding appurtenances), and methods proposed by the Contractor for correction of the conditions and lateral pipe re-establishment. In addition, the proposal shall describe perforations of existing culvert to be lined, their extent, and methods proposed for correction by the Contractor, including necessary grouting and backfilling. The proposal shall describe the Contractor's proposed procedures and schedules for installing the pipe liner and shall accompany the VHS format inspection recording required above.

For minor patching of small perforations, leave the paragraph below as is and full comp work into this item.

Perforations or spalls in the pipe wall shall be patched with cement mortar conforming to the requirements of Section 65-1.06 of the Standard Specifications. The mortar shall be allowed to dry prior to beginning placement of the spiral-wound PVC liner (expandable diameter).

The Contractor shall obtain the approval of the Engineer prior to beginning any repair work. Any work necessary, as determined by the Engineer, to repair the host prior to installation of the machine spiral-wound polyvinyl chloride (PVC) liner (expandable diameter) will be measured and paid for as extra work as provided in Section 4-1.03D of the Standard Specifications unless addressed elsewhere in these special provisions.

Installation of the machine spiral-wound polyvinyl chloride (PVC) liner (expandable diameter) shall be in accordance with ASTM Designation F-1741 using expandable profile liner pressed against existing pipe wall. The machine spiral wound pipe polyvinyl chloride (PVC) liner (expandable diameter) shall be wound directly into the existing culvert from an access point and expanded radially against the existing pipe after insertion. End seals, between the liner pipes and the existing pipe, shall be installed using Cement Mortar in conformance with the provisions in Section 65-1.06, "Joints," of the Standard Specifications.

The Contractor shall perform a CCTV inspection after the installation to establish that the lining has been installed as specified, there are no constrictions or deformities, and all live connections have been reinstated. The CCTV inspection of the lining will be performed in both directions (from each end of the culvert) to verify proper installation. A videotape of the CCTV inspection of the lining shall be made and shall be provided to the Engineer. The Engineer shall be allowed 10 working days to review the videotapes for both pre and post liner installation video inspections prior to approval of the work. If correction work is required to meet the installation recommendations of the manufacturer or to reestablish any live junctions, the Contractor shall perform this work at their own expense.

Machine spiral-wound polyvinyl chloride (PVC) liner (expandable diameter) work to be performed under these specifications will be listed in the contract item by size, type, or whatever information is necessary for identification. Quantities of the pipe liner shall be measured by the meter along the slope length of the host pipe as designated on the plans and confirmed by the Engineer. Liner placed in excess shall not be paid for.

Disconnecting of the existing downdrains, designated on the plans or encountered in the field, prior to the installation of the pipe liner may be required at some locations. Full compensation for disconnecting and reconnecting the existing downdrain shall be considered as included in the contract price paid per meter for the various sizes of Machine spiral-wound polyvinyl chloride (PVC) liner (expandable diameter) in the Engineer's estimate and no additional compensation will be allowed therefore.

The contract price paid per meter for the various sizes of machine spiral wound plastic pipe liners shall include full compensation for furnishing all labor, materials, tools, equipment, and incidentals, and for doing all the work involved in furnishing and installing the machine wound plastic pipe liners (expandable diameter), complete in place, controlling or diverting existing culvert flow, providing samples, cleaning of existing culverts of obstructions, repairing defects (except for removal of obstructions that cannot be removed by conventional equipment and cleaners), re-establishing all existing connections, cutting, removing, and disposing of a portion of host pipes where machine spiral-wound polyvinyl chloride (PVC) liner (expandable diameter) is to be installed and performing two closed circuit television inspections, complete in place, as shown on the plans, as specified in the Standard Specifications and these special provisions, and as directed by the Engineer.

SPIRAL WOUND POLYVINYL CHLORIDE (PVC) PIPE LINER (FIXED DIAMETER)

Spiral wound polyvinyl chloride (PVC) pipe liner (fixed diameter) shall be furnished and installed in existing culverts at the locations shown on the plans and in conformance with the details shown on the plans and these special provisions. Spiral wound polyvinyl chloride (PVC) pipe liner (fixed diameter) shall be wound directly into the existing culvert from an access point by machine (all pipe sizes) or internally by hand (human entry pipe sizes only).

Spiral wound polyvinyl chloride (PVC) pipe liner (fixed diameter) shall have a nominal diameter, thickness, as shown on the plans or as specified in these special provisions.

Spiral wound PVC pipe liner (fixed diameter) shall be manufactured from polyvinyl chloride (PVC) compounds and shall conform to the requirements for ribbed polyvinyl chloride (PVC) pipe in Section 64-1.02, "Materials" of the Standard Specifications. The profile type or initial stiffness factor shall be indicated on the plans or in the specifications.

PVC profile strip minimum dimensions and initial stiffness factors shall be in accordance with Table A below. Other profile configurations are permitted, provided similar details are provided as in Tables A, B and C.

Table A

Profile Type	Minimum Width mm	Minimum Height mm	Minimum Waterway Wall mm	Minimum Initial Stiffness Factor (EI) $MPa\text{-}mm^3$
7	121.0	19.0	2.1	$450x10^3$
8	86.0	24.0	2.1	$760x10^3$

The steel reinforcing shall be fabricated from AISI Type 316 stainless steel. The nominal width, nominal height, minimum strip thickness and minimum moment of inertia of the steel reinforcing profiles shall conform to Table B. Pipe stiffness shall conform to Table C. Other profile configurations are permitted, provided similar details are provided as in Tables B and C.

Table B

Profile Type	Nominal Width mm	Nominal Height mm	Minimum Strip Thickness mm	Minimum Moment of Inertia mm^4/mm
7S	60.0	16.0	0.7	2150
			0.9	2850
			1.2	4050
8S	60.0	21.0	0.9	5750
			1.2	7950

Table C

Outside Diameter (mm)	Pipe Stiffness (kPa) for Profile Type:						
	7	7S (0.7 mm)	7S (0.9 mm)	7S (1.2 mm)	8	8S (0.9 mm)	8S (1.2 mm)
600	50	440					
675	50	300	440				
750	40	210	310	420			
825	30	150	230	310			
900	30	120	180	230	60		
975	20	90	140	180	50	430	
1,050	20	70	110	140	40	350	470
1,125	20	60	90	120	30	290	390
1,200		50	70	100	30	250	330
1,350		30	50	70	20	180	240
1,400		30	40	60		170	220
1,500		20	40	50		140	190
1,600		20	30	40		120	160
1,700			20	30		100	140
1,800			20	30		90	120
1,900						80	100
2,000						70	90

A Certificate of Compliance shall be furnished to the Engineer in conformance with the provisions in Section 6-1.07, "Certificates of Compliance," of the Standard Specifications for each reel of PVC strip furnished. The certificate shall also include the manufacturer, plant, date of manufacture and shift, cell classification, unit mass, average pipe liner stiffness and profile type.

Each PVC continuous strip shall be distinctively marked on its inside surface at intervals not to exceed 1.5m with a coded number which identifies the manufacturer, minimum strip thickness, profile type, size, plant, date of manufacture and shift, cell classification and profile type. This information shall be visible from inside the completed liner and also appear on each reel.

Include the paragraph below if there will be a need to divert flow from the stream or storm drain during the course of the work. For very minor flows, leave as is and allow Contractor to develop a plan and include it in this item

of work. For significant flows or in environmentally sensitive locations, develop a separate item for Temporary Flow Diversion and show details of how it should be accomplished. If there will be no flows during construction, delete the paragraph below.

The Contractor shall provide for the control and diversion of flows in host pipes being rehabilitated. The bypass system shall be of adequate capacity and size to handle the flow. Prior to beginning any flow diversion work, the Contractor shall submit a plan showing the intended work, any calculations supporting the sizing of the system and a schedule indicating the duration of the flow diversion to the Engineer for approval.

The existing culvert shall be thoroughly cleaned of any obstacles prior to inserting the spiral wound PVC pipe liner (fixed diameter). Earthy material, trash, cuttings, and other waste materials removed from the existing culverts shall be disposed of in conformance with the provisions in Section 7-1.13, "Disposal of Material Outside the Highway Right of Way," of the Standard Specifications.

The existing culvert shall be inspected using a closed circuit television (CCTV) camera, and the inspection recorded on videotape as specified in these special provisions, and as directed by the Engineer. During this phase of operation all service openings shall be precisely located longitudinally and radially, and logged for subsequent reconnection after the insertion of the liner pipe.

Prior to beginning any pipe lining work, cleaning and inspecting all existing pipe shall be performed as specified elsewhere in these special provisions.After inspection of the existing pipe, the Contractor shall develop a written proposal describing the planned operations to repair the pipe. At a minimum, the proposal shall describe conditions found that may prevent proper installation of pipe liner (such as any sharp or protruding appurtenances), and methods proposed by the Contractor for correction of the conditions and lateral pipe re-establishment. In addition, the proposal shall describe perforations of existing culvert to be lined, their extent, and methods proposed for correction by the Contractor, including necessary void grouting and backfilling. The proposal shall describe the Contractor's proposed procedures and schedules for installing the pipe liner and shall accompany the VHS format inspection recording required above.

For minor patching of small perforations, leave the paragraph below as is and full comp work into this item.

Perforations or spalls in the pipe wall shall be patched with cement mortar conforming to the requirements of Section 65-1.06 of the Standard Specifications. The mortar shall be allowed to dry prior to beginning placement of the spiral-wound PVC liner (fixed diameter).

The Contractor shall obtain the approval of the Engineer prior to beginning any repair work Any work necessary, as determined by the Engineer, to repair the host prior to lining will be measured and paid for as extra work as provided in Section 4-1.03D of the Standard Specifications unless addressed elsewhere in these special provisions.

Installation of the spiral wound PVC pipe liner (fixed diameter) shall be in accordance with ASTM F-1741 using fixed diameter profile and F-1698. A continuous, one part, PVC ribbed liner profile strip with interlocking edges shall be used. Sealants and gaskets necessary for effective interlocking of the edges of PVC strip are pre-applied at the time of manufacture. The edges shall be locked together as the strip is wound into the pipe.

Installation of the spiral wound PVC pipe liner (fixed diameter) shall be in accordance with ASTM F-1741 using fixed diameter profile and F-1698. A continuous, one part, PVC ribbed liner profile strip reinforced with a continuous profiled steel strip with interlocking edges shall be used. Sealants and gaskets necessary for effective interlocking of the edges of PVC strip are pre-applied at the time of manufacture. The edges shall be locked together as the strip is wound into the pipe and the profiled steel band shall be mechanically locked onto the outside of the PVC profile liner pipe.

The spiral wound PVC pipe liner (fixed diameter) shall be wound at a fixed diameter, leaving an annular space between the liner and host pipe wall. The ends of the spiral wound PVC pipe liner (fixed diameter) shall be flush with the host pipe unless a beveled finished product is specified elsewhere in these special provisions.

The Contractor shall perform a CCTV inspection after the installation to establish that the lining has been installed as specified, there are no constrictions or deformities, and all live connections have been reinstated. The CCTV inspection of the lining will be performed in both directions (from each end of the culvert) to verify that the lining has been installed as specified and all live junctions have been reinstated. A video tape of the CCTV inspection of the lining shall be made and shall be provided to the Engineer. The Engineer shall be allowed 10 working days to review the video tapes for both pre and post liner installation video inspections prior to approval of the work. If correction work is required to meet the installation recommendations of the manufacturer or to reestablish any live junctions, the Contractor shall perform this work at their own expense.

The entire annular space between the spiral wound PVC pipe liner (fixed diameter) and the existing culvert shall be filled with grout. The Contactor shall notify the Engineer if the entire annular space between the spiral wound PVC pipe liner (fixed diameter) and the existing culvert cannot be filled with grout prior to starting work.

The grout (low density foam concrete) shall be composed of water, Portland cement, portland cement and fly ash, and/or additives, providing materials are not biodegradable, and a foaming agent is used. The foaming agent shall conform to the requirements in both of ASTM Designations: C-869 and C-796. Portland cement shall conform to the requirements of Section 90-2.01, "Cement," of the Standard Specifications.

The grout shall have a cast density, at the point of placement, of between 850 and 1090 kg/m^3 with a minimum penetration resistance of 690 kPa in 24 hours when tested in accordance with ASTM C-403 and a minimum compressive strength of 2070 kPa at 28 days. Compressive strength will be determined from test cylinders sampled, molded, cured, and tested in conformance with the provisions in Section 90-9, "Compressive Strength," of the Standard Specifications.

The water, cement, and fly ash, and/or additives shall be mixed prior to adding the foaming agent. The foaming agent shall not be added until the material is at the project site.

Before using grout for which the Contractor has determined the mix proportions, the Contractor shall submit in writing to the Engineer a copy of the mix design for approval. Certified test data or trial batch reports, verifying that the mix design complies with the density and compressive strength requirements of these special provisions, shall be submitted with the mix design. For each batch, the contractor shall perform density and viscosity tests per ASTM C-138 and ASTM C-939 in the presence of the Engineer. Grout that exceeds $\pm$ 48 kg/m^3 of the design density will be rejected. The time of efflux (outflow) shall not exceed 20 seconds in accordance with ASTM C-939 unless otherwise approved by the Engineer.

The Contractor shall develop and submit a grouting plan to the Engineer. Grouting shall not begin until the Engineer has approved the grouting plan. The Engineer will have 2 days for review of the grouting plan. The grouting plan shall address the numbered items below:

1) The proposed grouting mix
2) The proposed grout densities and viscosity
3) Initial set time of the grout
4) The 24-hour and 28-day minimum grout compressive strengths
5) The grout working time before a 15 percent change in density or viscosity occurs
6) The proposed grouting method and procedures
7) The maximum injection pressures (including last lift at the crown)
8) Proposed grout stage (lift) height and volumes (e.g., Stage 1, to spring line; Stage 2, fully grouted)
9) Bulkhead designs and locations
10) Buoyant force calculations during grouting and a detailed plan for holding the pipeliner on the invert of the existing pipe for a period of time long enough to allow the first lift of grout to set before proceeding to the second lift
11) Plans for diverting existing stream flow
12) Provisions for re-establishment of service connections
13) Pressure gauge, recorder, and field equipment certifications (e.g., calibration by an approved certified lab)
14) Proposed number and location of vents relative to pipe diameter and stiffness and the depth of flow in the pipeline for the grouting operation

15) Strut details
16) Proposed method for monitoring deformation of the pipeliner
17) Written confirmation that the Contractor has coordinated the grouting procedures with the grout installer and the pipeliner manufacturer.

Data for 1) through 5) shall be derived from trial grout batches as approved by the Engineer.

For each different type of grout or variation in procedure or installation, a complete package shall be submitted. The submittal shall include each of the above items and the locations or conditions to which it applies. The Contractor shall obtain approval from the Engineer for any changes to be made in grout mix, grouting procedure, or installation prior to commencement of grouting operations.

The gauged pumping pressure shall not exceed 35 kPa or manufacturer's recommendation for spiral wound PVC pipe liners (fixed diameter) with a pipe stiffness of less than 200 kPa and shall not exceed 50 kPa for all other PVC pipe liners (fixed diameter) without steel reinforcement. Grouting pressure shall not exceed 70 kPa for spiral wound steel reinforced PVC pipe liners (fixed diameter). In addition, the PVC pipeliner (fixed diameter) shall be able to withstand a static head of grout of 150 mm above the highest crown elevation. Maximum grout pressure for static grout head shall not exceed maximum allowable gauged pumping pressure for the PVC pipeliner (fixed diameter). The grout shall be placed in a continuous manner and injected in lifts not exceeding the height designated in the grouting plan approved by the Engineer, or less if needed to avoid floating, shifting or deforming the PVC pipeliner (fixed diameter). The injection pressure including the last lift at the crown shall be carefully monitored. If the PVC pipeliner (fixed diameter) cannot withstand the grouting pressures or static head, then the maximum pressure at the point of grout injection must be reduced or staged grouting must be employed, or an alternative pipeliner selected. Deformation the PVC pipeliner (fixed diameter) shall not exceed 5%. The Contractor's placement method shall prevent segregation or voids from occurring in the grout mix.

Prior to grouting, the existing culvert shall be free from water and debris. Grouting shall not begin until the existing stream flow has been temporarily diverted and approved bulkheads installed. Grout injection tubes and breather tubes shall be placed around the liner and through the bulkheads.

As approved by the Engineer, grout injection holes of up to 50 mm in diameter may also be drilled at appropriate points in the spiral wound PVC pipe liner (fixed diameter), plugged with PVC plugs and sealed in place with a bead of approved sealant/adhesive.

Spiral-wound PVC liner (fixed diameter) work to be performed under these specifications will be listed in the contract item by size, type, or whatever information is necessary for identification. Quantities of the pipe liner shall be measured by the meter along the slope length of the host pipe as designated on the plans and confirmed by the Engineer. Spiral-wound polyvinyl chloride PVC liner (fixed diameter) placed in excess shall not be paid for. Upon completion of installing the spiral wound PVC pipe liner (fixed diameter) including annular space grouting, ends of the pipe shall be sealed with cement mortar conforming to the provisions in Section 65-1.06, "Joints," of the Standard Specifications. When beveled ends are shown on the plans, exact dimension in millimeters between end of host pipe and spiral-wound PVC liner (fixed diameter), to be determined by the Engineer prior to sealing ends with cement mortar.

Disconnecting of the existing downdrains, designated on the plans or encountered in the field, prior to the installation of the pipe liner may be required at some locations. Full compensation for disconnecting and reconnecting the existing downdrain shall be considered as included in the contract price paid per meter for the various sizes of spiral-wound polyvinyl chloride (PVC) liner (fixed diameter) in the Engineer's estimate and no additional compensation will be allowed therefore.

The contract price paid per meter for the different sizes of spiral wound PVC pipe liner (fixed diameter) shall include full compensation for furnishing all labor, materials (including grout), tools, equipment, and incidentals, and for doing all the work involved in installing spiral wound PVC pipe liner (fixed diameter), complete in place, including cleaning of existing culverts of obstructions, re-establishing all existing connections, annular space grouting, providing samples, repairing defects (except for removal of obstructions that cannot be removed by conventional equipment and cleaners), cutting, removing, and disposing of a portion of host pipes where spiral-wound PVC liner (fixed diameter) is to be installed and performing two closed circuit television inspections, grouting and submitting the grout mix design and grouting plan, diverting existing stream flow, cleaning existing culverts and disposal of residue from cleaning, as shown on the plans, as specified in the Standard Specifications and these special provisions, and as directed by the Engineer.

The entire annular space between the spiral-wound polyvinyl chloride PVC liner (fixed diameter) and the existing culvert shall be filled with grout. A minimum dimension of 75 mm between the liner and the host pipe shall be maintained all around the liner. The Contactor shall notify the Engineer if the minimum dimension cannot be obtained prior to starting work.

The grout shall conform to the requirements of Section 50-1.09, "Bonding and Grouting," of the Standard Specifications and may include clay, chemicals, sand, or other admixtures such as fly ash, which shall conform to the requirements of Section 90-4, "Admixtures," of the Standard Specifications.

The grout shall have a minimum compressive strength of 7 N/mm^2 at 7 days, and 12 N/mm^2 at 28 days. Compressive strength for each grout lift shall be determined from test cylinders sampled, molded, cured, and tested in conformance with the provisions in Section 90-9, "Compressive Strength," of the Standard Specifications.

The Contractor shall determine the mix proportions of the grout. If sand is allowed or required, a minimum of 25% by mass of the total amount of the cementitious material shall be fly ash, and the total amount of mineral admixture shall not exceed 35 percent by mass of the total amount of cementitious material to be used in the mix.

Before using grout for which the Contractor has determined the mix proportions, the Contractor shall submit in writing to the Engineer a copy of the mix design for approval. Certified test data or trial batch reports, verifying that the mix design complies with the density and compressive strength requirements of these special provisions, shall be submitted with the mix design. For each batch, the contractor shall perform density and viscosity tests per ASTM C-138 and ASTM C-939 in the presence of the Engineer. Grout that exceeds $\pm$ 48 kg/m^3 of the design density will be rejected. The time of efflux (outflow) shall not be less than 11 seconds or exceed 20 seconds in accordance with ASTM C-939 unless otherwise approved by the Engineer.

The Contractor shall develop and submit a grouting plan to the Engineer. The grouting plan shall address the numbered items below. Grouting shall not begin until the Engineer has approved the grouting plan. The Engineer will have 2 days for review of the grouting plan.

1) The proposed grouting mix
2) The proposed grout densities, viscosity and shrinkage
3) Initial set time of the grout
4) The 7-day and 28-day minimum grout compressive strengths
5) The grout working time before a 15 percent change in density or viscosity occurs
6) The proposed grouting method and procedures
7) The maximum injection pressures (including last lift at the crown)
8) Proposed grout stage (lift) height and volumes (e.g., Stage 1, to spring line; Stage 2, fully grouted)
9) Bulkhead designs and locations
10) Buoyant force calculations during grouting and a detailed plan for holding the pipeliner on the invert of the existing pipe for a period of time long enough to allow the first lift of grout to set before proceeding to the second lift
11) Plans for diverting existing stream flow
12) Provisions for re-establishment of lateral connections
13) Pressure gauge, recorder, and field equipment certifications (e.g., calibration by an approved certified lab)
14) Proposed number and location of vents relative to pipe diameter and stiffness and the depth of flow in the pipeline for the grouting operation
15) Strut details
16) Proposed method for monitoring deformation of the pipeliner
17) Written confirmation that the Contractor has coordinated the grouting procedures with the grout installer and the pipeliner manufacturer.

Data for 1) through 5) shall be derived from trial grout batches as approved by the Engineer. For each different type of grout or variation in procedure or installation, a complete package shall be submitted. The submittal shall include each of the above items and the locations or conditions to which it applies. The Contractor shall obtain approval from the Engineer for any changes to be made in grout mix, grouting procedure, or installation prior to commencement of grouting operations.

The gauged pumping pressure shall not exceed 35 kPa or manufacturer's recommendation for spiral wound PVC pipe liners (fixed diameter) with a pipe stiffness of less than 200 kPa and shall not exceed 50 kPa for all other PVC pipe liners (fixed diameter) without steel reinforcement. Grouting pressure shall not exceed 70 kPa for spiral wound PVC pipe liners (fixed diameter) with steel reinforcement. In addition, the PVC pipeliner (fixed diameter) shall be able to withstand a static head of grout of 150 mm above the highest crown elevation. Maximum grout pressure for static grout head shall not exceed maximum allowable gauged pumping pressure for the spiral wound PVC pipe liner (fixed diameter). The grout shall be placed in a continuous manner and injected in lifts not exceeding the height designated in the grouting plan approved by the Engineer, or less if needed to avoid floating, shifting or deforming the spiral wound PVC pipe liner (fixed diameter). The injection pressure including the last lift at the crown shall be carefully monitored. If the spiral wound PVC pipe liner (fixed diameter) cannot withstand the grouting pressures or static head, then the maximum pressure at the point of grout injection must be reduced or staged grouting must be employed, or an alternative pipeliner selected. Deformation the spiral wound PVC pipe liner (fixed diameter) shall not exceed 5%. The Contractor's placement method shall prevent segregation or voids from occurring in the grout mix.

Prior to grouting, the existing culvert shall be free from water and debris. Grouting shall not begin until the existing stream flow has been temporarily diverted and approved bulkheads installed. Grout injection tubes and breather tubes shall be placed around the liner and through the bulkheads.

As approved by the Engineer, grout injection holes of up to 50 mm in diameter may also be drilled at appropriate points in the spiral wound PVC pipe liner (fixed diameter), plugged with PVC plugs and sealed in place with a bead of approved sealant/adhesive.

Spiral-wound PVC liner (fixed diameter) work to be performed under these specifications will be listed in the contract item by size, type, or whatever information is necessary for identification. Quantities of the pipe liner shall be measured by the meter along the slope length of the host pipe as designated on the plans and confirmed by the Engineer. Spiral-wound polyvinyl chloride PVC liner (fixed diameter) placed in excess shall not be paid for. Upon completion of installing the spiral wound PVC pipe liner (fixed diameter) including annular space grouting, ends of the pipe shall be sealed with cement mortar conforming to the provisions in Section 65-1.06, "Joints," of the Standard Specifications. When beveled ends are shown on the plans, exact dimension in millimeters between end of host pipe and spiral-wound PVC liner (fixed diameter), to be determined by the Engineer prior to sealing ends with cement mortar.

Disconnecting of the existing downdrains, designated on the plans or encountered in the field, prior to the installation of the pipe liner may be required at some locations. Full compensation for disconnecting and reconnecting the existing downdrain shall be considered as included in the contract price paid per meter for the various sizes of spiral-wound PVC liner (fixed diameter) in the Engineer's estimate and no additional compensation will be allowed therefore.

The contract price paid per meter for the different sizes of spiral wound PVC pipe liner (fixed diameter) shall include full compensation for furnishing all labor, materials (including grout), tools, equipment, and incidentals, and for doing all the work involved in installing spiral wound PVC pipe liner (fixed diameter), complete in place, including cleaning of existing culverts of obstructions, re-establishing all existing connections, annular space grouting, providing samples, repairing defects (except for removal of obstructions that cannot be removed by conventional equipment and cleaners), cutting, removing, and disposing of a portion of host pipes where spiral-wound PVC liner (fixed diameter) is to be installed and performing two closed circuit television inspections, grouting and submitting the grout mix design and grouting plan, diverting existing stream flow, cleaning existing culverts and disposal of residue from cleaning, as shown on the plans, as specified in the Standard Specifications and these special provisions, and as directed by the Engineer.

Cement mortar conforming to the provisions in Section 65-1.06, "Joints," of the Standard Specifications, shall be placed to form a seal between the existing culvert and the spiral wound PVC pipe liner, as shown on the plans. Pipe for the weep tube shall be commercial quality, rigid, plastic pipe. When beveled ends are shown on the plans, exact dimension in millimeters between end of host pipe and spiral-wound PVC liner (fixed diameter), to be determined by the Engineer prior to sealing ends with cement mortar.

Paper or cloth wadding shall be placed not less than 150 mm from each end of the existing pipe, as shown on the plans, to retain the mortar during sealing operations.

Spiral-wound polyvinyl chloride (PVC) liner (fixed diameter) work to be performed under these specifications will be listed in the contract item by size, type, or whatever information is necessary for identification. Quantities of the pipe liner shall be measured by the meter along the slope length of the host pipe as designated on the plans and confirmed by the Engineer. Liner placed in excess shall not be paid for.

Disconnecting of the existing downdrains, designated on the plans or encountered in the field, prior to the installation of the pipe liner may be required at some locations. Full compensation for disconnecting and reconnecting the existing downdrain shall be considered as included in the contract price paid per meter for the various sizes of spiral-wound polyvinyl chloride (PVC) liner (fixed diameter) in the Engineer's estimate and no additional compensation will be allowed therefore.

APPENDIX H:
Cone Penetration Test (CPT) Investigations

H.1 Introduction

Cone penetration test (CPT) is a field test in which a 1.75-inch (44.5-mm) diameter steel shaft with a 60˚ conical tip is hydraulically pushed into the ground to collect various subsurface data. This technology, developed originally in Europe, is becoming a premier subsurface exploration method in North America for the fields of geotechnical engineering, earthquake engineering, and environmental engineering. The rising popularity of CPT is due to the fact that it can provide much higher resolution data than any of the conventional test methods (such as SPT). CPT is cleaner than the traditional drilling based methods, bringing no spoil to the ground surface. The probe located near the tip can accept many different sensors and devices to acquire project specific subsurface information. The standard CPT cone is equipped with strain-gage-based load cells and a pressure transducer to measure the tip resistance, sleeve friction, and pore pressure – See Figure H.1. Publications by Meigh (1987) and Robertson and Campanella (1988) describe the procedures and data interpretation methods for CPT.

G.2 CPT Sounding at Highway Culvert Sites

In the current research project, CPT technology was applied at three highway culvert sites in Ohio (listed in Table H.1). The first culvert structure (WAR-48-20.95) was a 55-inch (1,397 mm) diameter corrugated metal pipe. It was not part of the field inspection program involved in the study. This structure was suggested for the CPT investigation phase of the project by ODOT personnel who happened to notice its poor conditions despite its young age. The remaining two culverts were thermoplastic pipe culverts, that had been inspected in the current research project. Their descriptions and conditions have been presented previously in Chapters 6 and 7. The following sections provide details of the CPT sounding work performed at each of these sites.

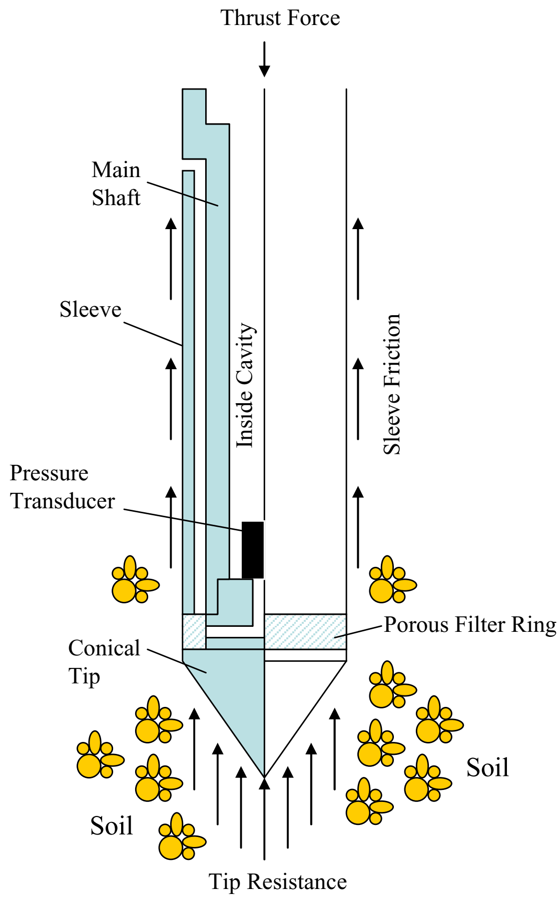


Figure H.1: CPT Penetration Process in Subsurface

Table H.1: List of Culverts Selected for CPT Application

No.	Culvert	Culvert Size	Ht. of Cover	Notes
1	WAR-48-20.95 (Corrugated Metal)	55" (1,397 mm) Dia.	Approx. 10 ft (3.0 m)	Installed in #8 stone. CPT performed on 11-10-05
2	FAI-33b-Sta. 446+92 (HDPE Pipe)	60" (1,524 mm) Dia.	Approx. 8 ft (2.4 m)	Installed in sand. CPT performed on 3-4-05
3	FAI-33b-Sta. 587+96 (PVC Pipe)	48" (1,219 mm) Dia.	Approx. 17 ft (5.2 m)	Installed in crushed limestone. CPT performed on 3-4-05

H.2.1 CPT Sounding at WAR-48-20.95 Culvert Site

H.2.1.1 Initial Inspection of WAR-48-20.95

A reconnaissance trip was made to the site of the metal culvert WAR-48-20.95 on Oct. 8, 2004. The culvert was located just south of a new bridge constructed on Rt. 48, on the north edge of the City of Lebanon, Ohio. This culvert structure was installed in 2003. No drainage flow was taking place through the culvert. The metal surface looked new with no indication of corrosion or pitting anywhere. Some observations made at the site were:

- The culvert consisted of three sections of a non-sectional corrugated metal pipe with a continuous spiral seam running through it. The corrugated plate had a pitch of 2-5/8" (67 mm), depth of ½" (13 mm), and a thickness of 0.075" (2 mm). The culvert had a steep slope of 9.5%.

- The cross-sectional shape of the culvert looked distorted and unsymmetrical near Joint 1 (near the outlet end) and near Joint 3 (near the inlet end).

- At Joint 1, a gap was present on the invert. The gap appeared to be contained with a metal coupler. At Joint 3 (close to the inlet end), a 1-inch or 25-mm offset and a gap existed on the invert. The bedding material (coarse stones) was visible through the gap.

- The headwall at the inlet end was a half-height concrete cradle. The headwall at the outlet end was a tall retaining wall. No major cracks or signs of movement/rotation were observed on either of the headwalls.

- The maximum height of cover appeared to be about 10 ft (3.05 m).

- The roadway surface was smooth and free from any dips/cracks.

The diameter measurements taken inside the culvert are presented in Table H.2. The table indicates that the worst distortion existed near Joint 1. Photographs taken at the site during the reconnaissance trip are presented below.

Table H.2: Inside Diameters of WAR-48-20.95

Distance from Outlet End	Vertical:		Horizontal:	
	Diameter (in.)	Deflection (%)	Diameter (in.)	Deflection (%)
0 (Outlet End)	56.00	+ 3.7	53.00	- 1.9
5 ft	55.25	+ 2.3	52.75	- 2.3
13 ft	53.00	- 1.9	52.375	- 3.0
24 ft (Near Joint 1)	48.50	- 10.2	56.00	+ 3.7
50 ft (Near Joint 2)	53.25	- 1.4	54.50	+ 0.9
75 ft (Near Joint 3)	52.25	- 3.2	54.25	+ 0.5
85 ft	54.75	+ 1.4	55.00	+ 1.9
100 ft	54.125	+ 0.2	54.00	0.0
102 ft (Inlet End)	54.25	+ 0.5	55.00	+ 1.9

[Note] 1 inch = 25.4 mm; and 1 ft = 0.305 m

Figure H.1: General View of Outlet End

Figure H.2: Cross-sectional Shape of Culvert at Joint 1 (Near Outlet)

Figure H.3: Joint Condition at Invert of Joint 1

Figure H.4: Another View of Culvert Shape Taken Near Joint 1

Figure H.5: General View of Culvert Shape Taken at Mid-Length (Looking Toward Outlet End)

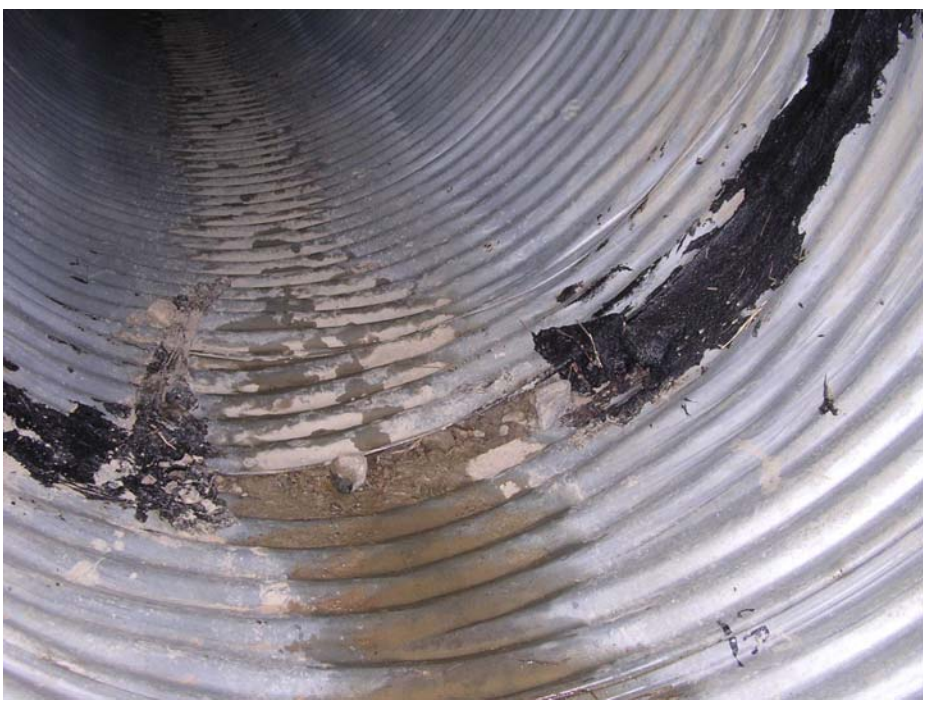


Figure H.6: Gap and Offset Detected at Joint 3 (Near Inlet End)

Figure H.7: General View of Culvert Shape at Inlet End

Figure H.8: General View of Culvert & Headwall at Inlet End

Figure H.9: General View of Roadway Surface Over Culvert

Figure H.10: Close-Up View of Pavement Surface Over Culvert

(Note: The white dot on the asphalt surface corresponds to the culvert crown at Joint 1)

Based on the inspection work conducted during the reconnaissance trip, it was decided that the CPT sounding should be conducted near either Joint 1 or Joint 3 of the culvert. Joint 1 is located under the white paint mark made on the asphalt surface (as shown in Figures H.9 and H.10 above). Joint 3 is located under the large grassed area away from the traffic lanes. Joint 1 location is preferable, since the CPT work there will require closing of only one traffic lane.

G.2.1.2 CPT Sounding at WAR-48-20.95

The CPT sounding work was performed at the culvert WAR-48-20.95 on Nov. 10, 2004. According to ODOT personnel:

- The original culvert was supposed to withstand up to 60 ft (18.3 m) of soil fill load when installed properly.
- One question concerning this culvert was if it had been damaged before it was buried in the ground.
- The culvert was rehabilitated 2 weeks prior to the CPT investigation. The contractor who performed the rehabilitation work excavated the inlet end area, removed the top part of the culvert through cutting, inserted a 42-inch (1.07-m) diameter, 0.5-inch (13-mm) thick, solid-wall steel pipe, and grouted the gap.
- Before inserting the steel pipe, the contractor drilled small holes over the invert at 4, 6, and 8 o'clock positions every 5 ft (1.52 m) along the culvert length to inject polyurethane into the bedding layer to fill voids in it and stabilize it.
- The culvert was supposedly backfilled with ODOT Item 304. However, when the inlet section was excavated, they found AASHTO #8 stones in the area.
- The trench width was not measured but was believed to be fairly wide.

As soon as the traffic control was set up by ODOT to close one traffic lane, two CPT hole locations were marked on the asphalt pavement surface near Joint 1, using white spray paint. A plumb-bob was dropped to the culvert outlet end from the roadway edge to mark the crown of the culvert along the east edge of the road. A level rod was set up at the culvert inlet end to establish the crown position along the western edge of the road. Using these two reference points, a 100-ft (30.5-m) tape was stretched tightly across the pavement surface. The crown at Joint 1 was marked on this tape by pacing a distance of 24 ft (7.32 m) from the outlet end. Then, the two hole locations were spray-painted on the roadway surface by taking a distance of 4.5 ft (1.37 m) in each direction, perpendicularly to the projected culvert centerline. According to the estimations, the CPT probe should be penetrating through the backfill soil about 2 ft (0.61 m) away from the culvert. Figure H.11 illustrates the locations of the two CPT holes with respect to the roadway and culvert. The hole on the north side was identified as Hole #1, and the hole on the south side was identified as Hole #2. The second task was to punch a hole through the 12-inch (0.30 m) thick AC layer at each hole location. This was done using a hammer drill. It took less than 30 minutes to drill 2-inch (50-mm) diameter holes through the AC layer at the Hole #1 and #2 locations.

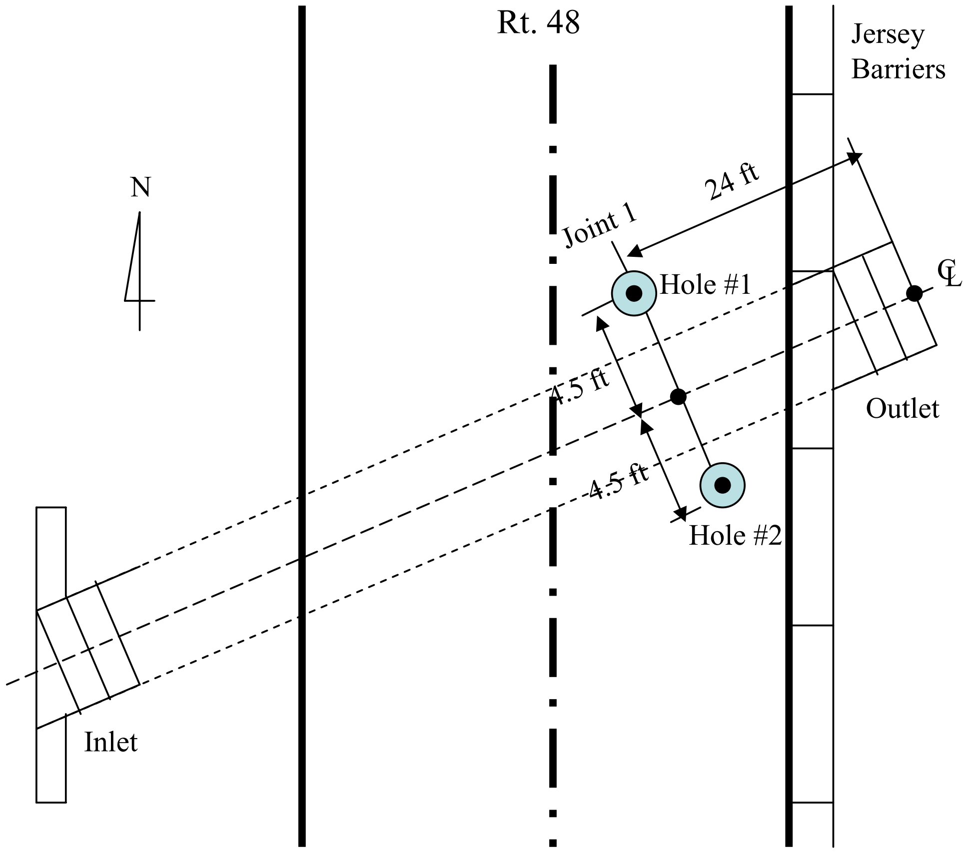


Figure H.11: CPT Hole Location Plan (WAR-48-20.95)

First CPT Hole (Hole #2)

The CPT sounding at Hole #2 began at 10:20 p.m. The goal was to reach a minimum depth of 20 ft (6.10 m) or the top of bedrock, whichever was shallower. One member of the team, equipped with a portable radio communication device, stayed inside the culvert during the sounding. This precautionary measure was taken in case the CPT probe would somehow penetrate down toward the top of culvert. The dummy cone was pushed 12 inches (0.30 m) into the soil to establish a start-up hole. Figure H.12 presents a CPT log that resulted from the sounding in Hole #2.

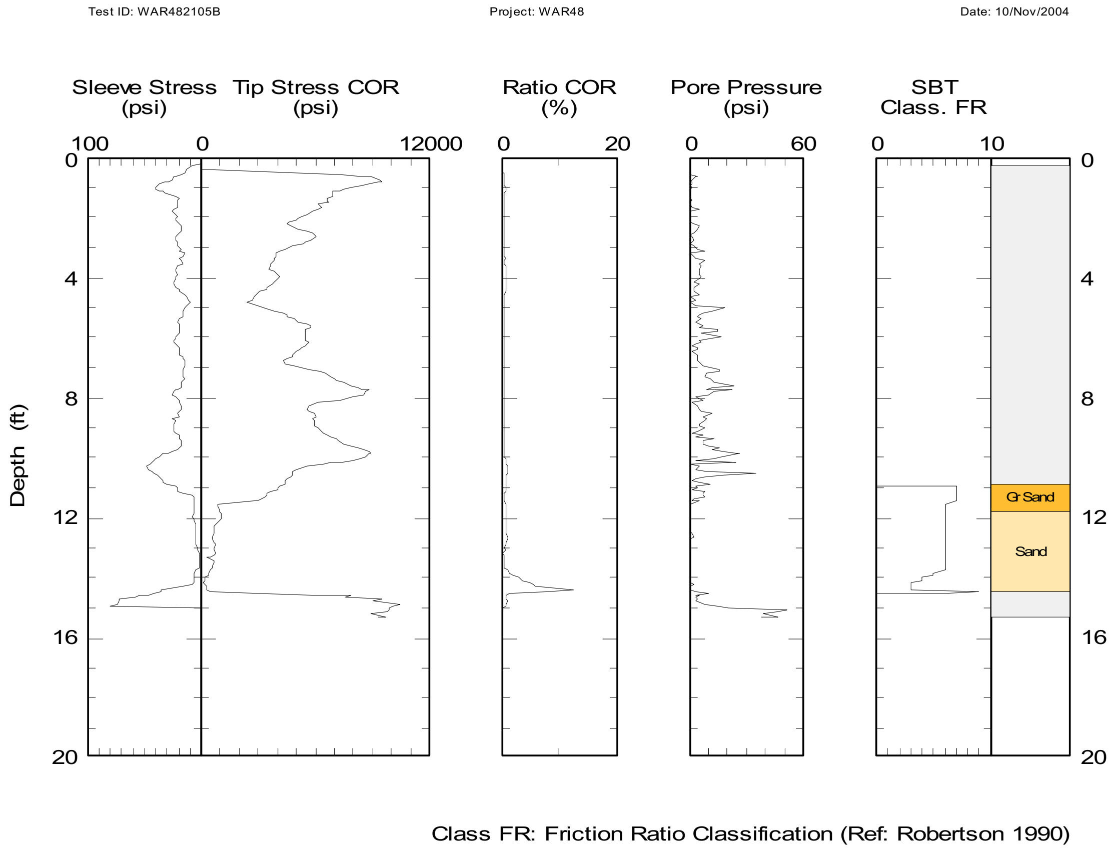


Figure H.12: CPT Log for Hole #2 at WAR-48-20.95

In the standard CPT log:

Sleeve Stress (f_s) = Side friction force acting over the sleeve, divided by the total surface area of the sleeve. Measured by strain gages installed on the sleeve. Cohesionless soils should exert little side friction force on the sleeve, while a measurable friction force should develop while penetrating through any cohesive soil. 1 psi = 6.894 kPa.

Tip Stress COR (q_c) = Force acting against the conical tip, divided by the total projected area of the tip and corrected for pore water effect. Measured by strain gages installed on main shaft. The correction is required especially for saturated weak clayey soils to make sure that the tip stress is always at least as large as the pore pressure. This measurement may be mainly a reflection of the relative density of the material in front of the tip. 1 psi = 6.894 kPa.

Ratio COR = Ratio of sleeve stress divided by the corrected tip stress. The lower this ratio is, more cohesionless (or granular) the soil should be.

Pore Pressure (u) = Pore water pressure measured by a pressure transducer housed inside the cone assembly. Cavity leading to the transducer is located right behind the conical tip. This reading should reflect the hydrostatic pressure (that increases linearly with depth) while penetrating through any permeable zone below the groundwater table. Excess pore pressure, that is much larger than the hydrostatic pressure, tends to develop while penetrating through any zone of low permeability. 1 psi = 6.894 kPa.

SBT = Standardized (normalized) friction ratio. Based on the following formula:

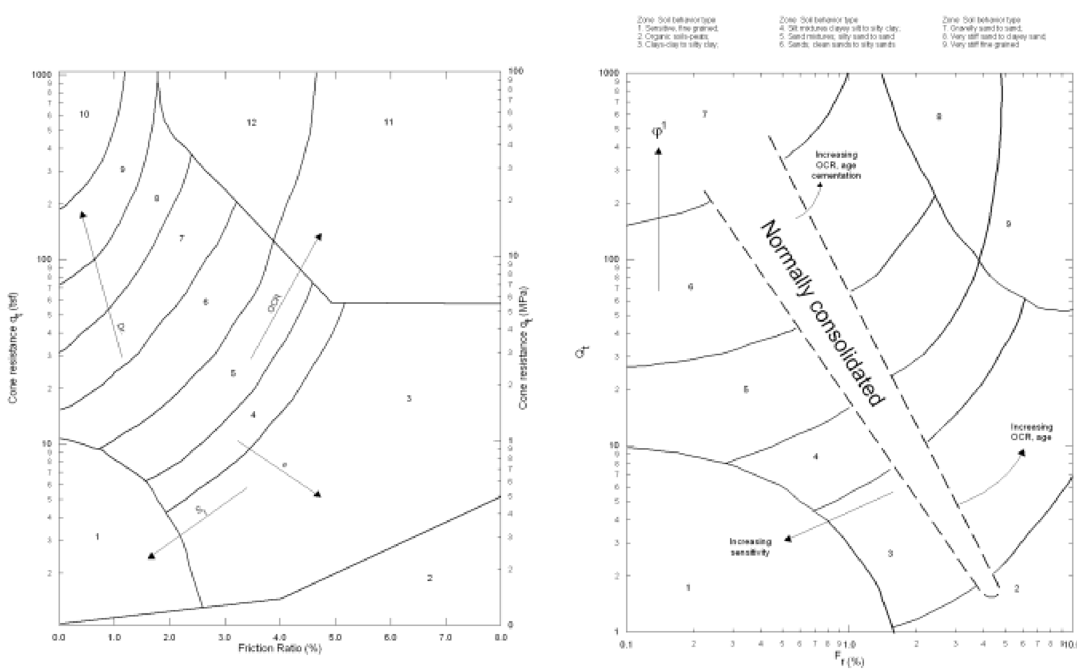
$$SBT(\%) = \frac{f_s}{q_c - \sigma_{v0}} x100$$

where σ_{v0} = effective overburden stress.

Class. FR = Soil behavioral classification based on a chart by Robertson (1990).

OC	= Very stiff (or overconsolidated) fine-grained soil.
Cl Silt	= Normally consolidated clayey silt to silty clay.
OC-Clay	= Very stiff (or overconsolidated) clay.
Gr Sand	= Normally consolidated gravely sand to sand.

Once the CPT readings are obtained, a chart similar to the one shown in Figure H.13 is used to identify the type of soil encountered at any depth.



(Modified from Robertson et al, 1986) (Modified from Robertson et al, 1990)

Figure H.13: Soil Behavioral Classification Chart

The culvert was believed to be located from 10 ft (3.1 m) to 15 ft (4.6 m) below the ground surface. According to the log, the soil behavioral classification method based on CPT readings identified the backfill to be a sandy soil. Both tip resistance (q_c) and sleeve friction (f_s) readings decreased significantly from the depth of 10 ft (3.05 m). The probe encountered the bedrock at the depth of 14 ft (4.27 m). The truck started lifting itself off the roadway surface. The sounding of Hole #2 was completed at 11:50 a.m.

Second CPT Hole (Hole #1)

The CPT sounding began at Hole #1 at 12:00 p.m. The goal was to reach a minimum depth of 20 ft (6.10 m) or the top of bedrock, whichever was shallower. One of the team members stayed inside the culvert again as a precautionary measure. The dummy cone was pushed 12 inches (0.30 m) into the soil. Figure H.14 presents a CPT log that resulted from the sounding in Hole #1. The culvert was believed to be located from 10 ft (3.1 m) to 15 ft (4.6 m) below the ground surface. The backfill soil type was recognized again correctly in the log. According to the log, both tip resistance (q_c) and sleeve friction (f_s) readings decreased significantly from the depth of 12 ft (3.66 m). The probe encountered a very stiff layer at 14.7 ft (4.48 m). The truck started lifting off the roadway surface. The sounding of Hole #1 was completed at 12:30 a.m.

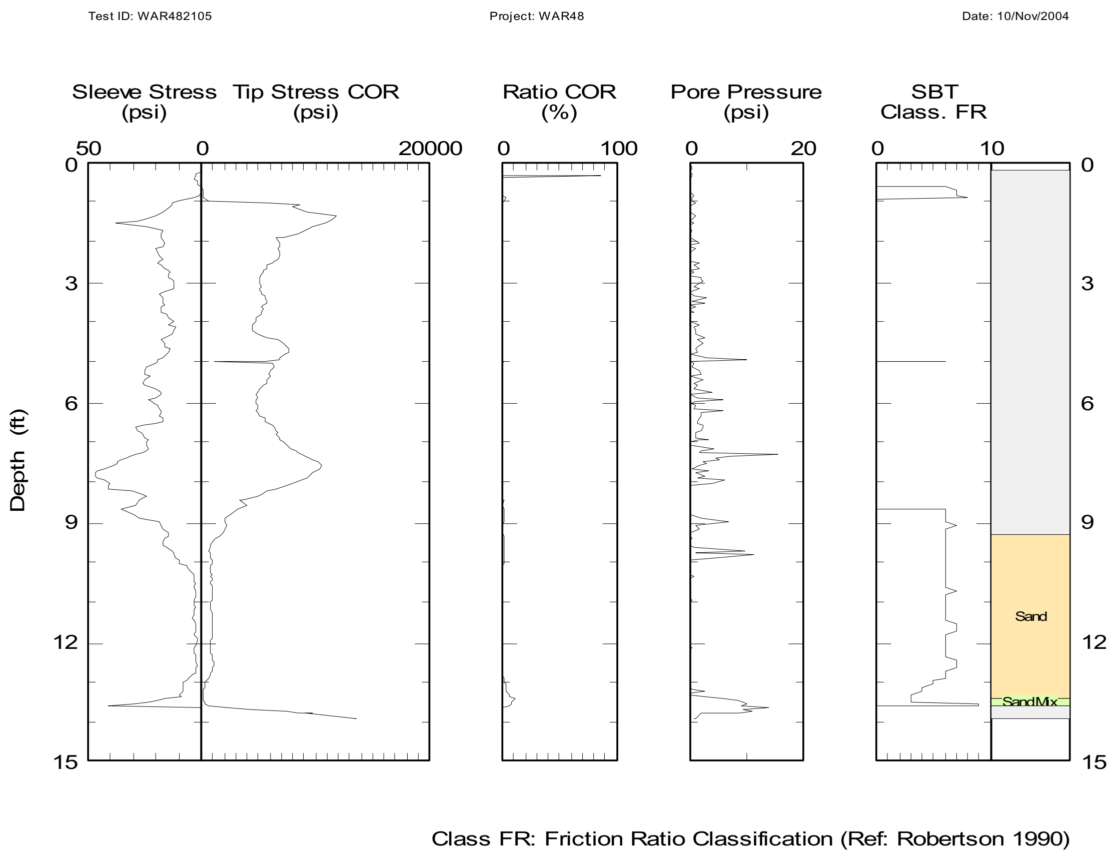


Figure H.14: CPT Log for Hole #1 at WAR-48-20.95

Observations at WAR-48-20.95

The team felt that the CPT sounding work conducted at this site was successful. The fact that the CPT readings decreased significantly while penetrating the backfill soil below the crown elevation indicated the presence of loose backfill zone next to the culvert. According to the way the culvert had deformed, it was leaning toward south. This leaning might have compacted the backfill on the south (Hole #2) side somewhat more and loosened the backfill on the north (Hole #1) side. Figure H.15 plots the tip resistance stress measurements recorded in both holes. Figure H.16 plots the tip resistance stress ratio (Hole #1)/(Hole #2) over the depth range. When these plots are examined closely, it is realized that the tip resistance readings were indeed higher on the south (Hole #2) side at the depth range corresponding to the culvert depth and rise.

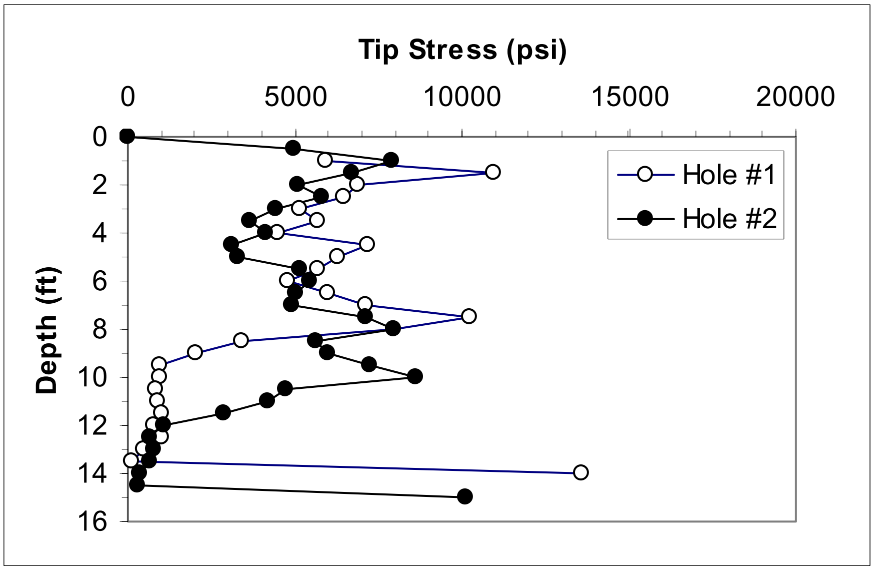


Figure H.15: Tip Resistance Stress Measurements at WAR-48-20.95

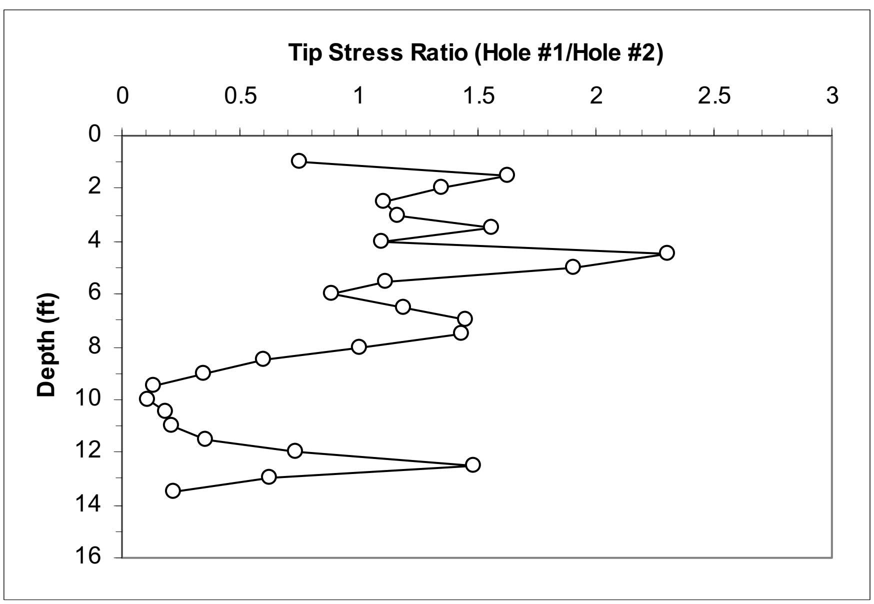


Figure H.16: Tip Resistance Stress Ratio Between Holes #1 and #2

Several color photographs taken before the field work at this site are attached here.

Figure H.17: Inlet End of Rehabilitated Culvert

Figure H.18: Interior View of Rehabilitated Culvert

Figure H.19: Two CPT Hole Locations Marked on Pavement

Figure H.20: Dummy Cone Positioned Above Hole #2 Location

Figure H.21: Hammer Drill Used To Break Through AC Layer

Figure H.22: Hole Drilled Through AC

H.2.2 CPT Sounding at FAI-33b-Sta. 446+92

A reconnaissance trip to the site of this 60-inch (1.52-m) diameter HDPE pipe was made on February 16, 2005. The CPT work was performed at this culvert location on March 4, 2005. As it was reported earlier in Chapter 6, the inspection team found this culvert to be in poor conditions, experiencing up to 8% deflections and exhibiting localized buckling of liner at the springline positions. Prior to conducting CPT, the asphalt concrete layer was cored with a portable coring device. Figures H.23 through H.27 are the photographs taken during the field work. The CPT log obtained at this site is shown in Figure H.28. The culvert was believed to be located from 8 ft (2.44 m) to 14 ft (4.27 m) below the ground surface. According to the log, the backfill material was categorized as a sandy soil based on the CPT soil behavioral classification method. Tip resistance stress recorded in the depth range corresponding to the culvert location and size was mostly less than 400 psi (2.76 MPa).

Figure H.23: Coring of Asphalt Concrete Layer

Figure H.24: CPT Truck Parked in Shoulder Section

Figure H.25: CPT Truck Positioned over FAI-33b-Sta. 446+92

Figure H.26: CPT Getting Ready to Penetrate into Ground

Figure H.27: Hydraulic Push Frame Operating Inside CPT Truck

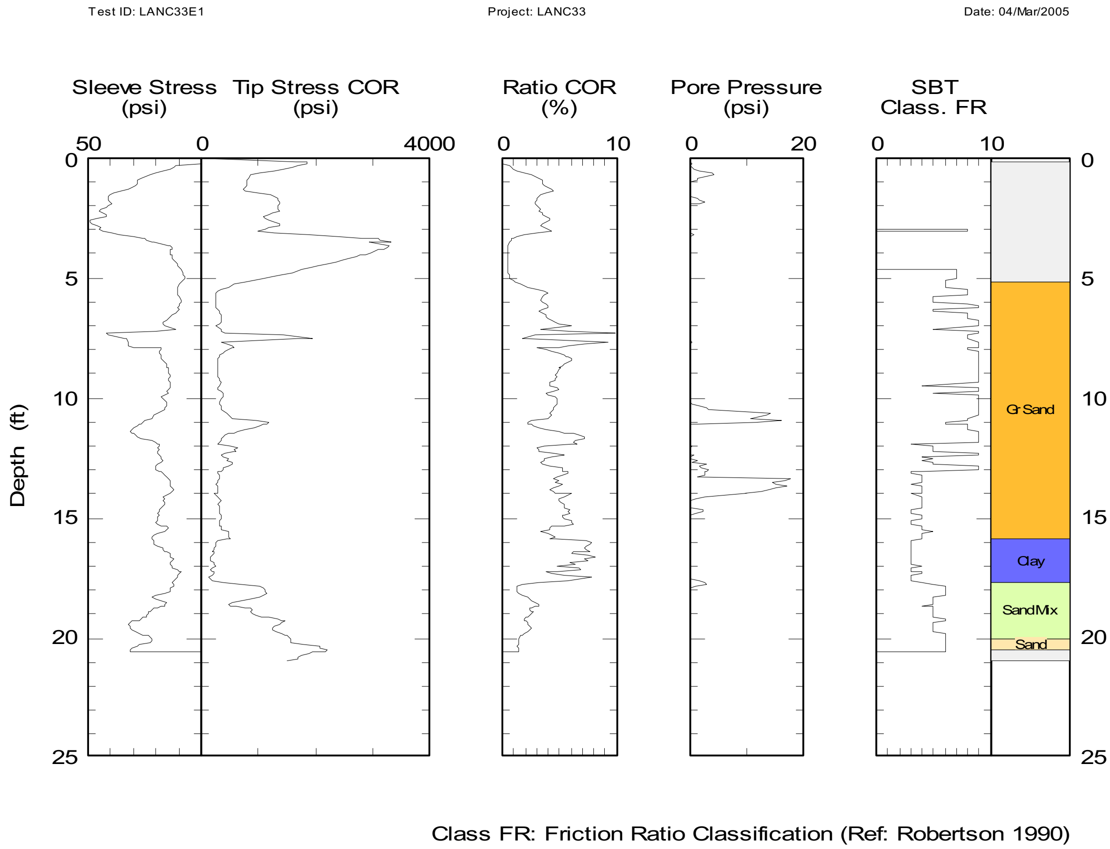


Figure H.28: CPT Log for Culvert FAI-33b-Sta. 446+92

G.2.3 CPT Sounding at FAI-33b-Sta. 587+96

A reconnaissance trip to the site of this 48-inch (1.22-m) diameter PVC pipe was made on February 16, 2005. The CPT work was performed at this culvert location on March 4, 2005. As it was reported earlier in Chapter 6, the inspection team found this culvert to be in good conditions, exhibiting no cracks anywhere and deflections of less than 5%. Prior to conducting CPT, the asphalt concrete layer was cored with a portable coring device. Figure H.29 is a photograph taken during the field work. The CPT log obtained at this site is shown in Figure H.30. The culvert was believed to be located from 17 ft (5.2 m) to 22 ft (6.7 m) below the ground surface. According to the log, the tip resistance remained less than 500 psi (3.45 MPa) from the depth of 11 ft to 23 ft (3.35 m to 7.01 m). The crushed limestone material was identified as either sand mix or clayey silt by the CPT soil behavioral classification method.

Figure H.29: CPT Truck Positioned over FAI-33b-Sta. 587+96

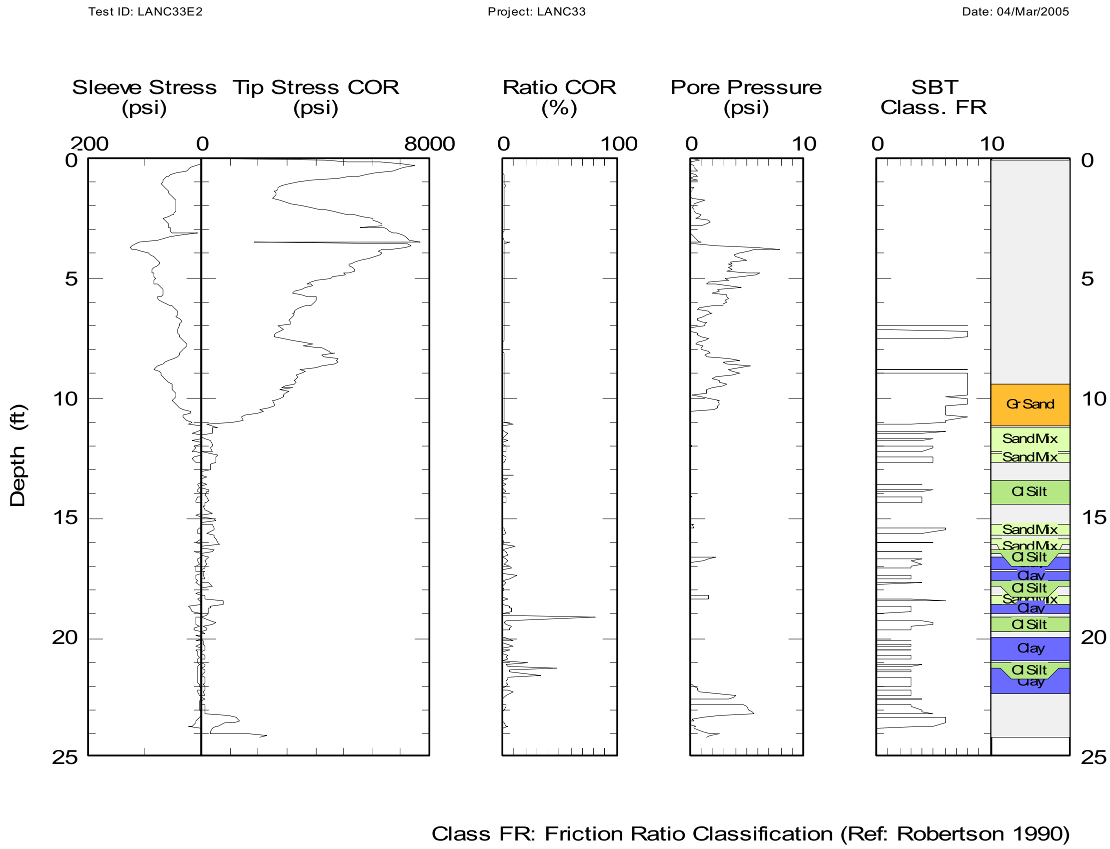


Figure H.30: CPT Log for FAI-33b-Sta. 587+96

G.3 Concluding Remarks

During the current research project, it was demonstrated at the three highway culvert sites that the cone penetration test (CPT) can be a useful tool for evaluating the quality of backfill soil envelope placed around the culvert. The zone of weak (or loose) soil or voids near the culvert can be easily identified, without open excavation, through significant declines in the tip resistance (q_c) and sleeve friction (f_s) readings. From the CPT readings the type of backfill soil can be estimated (if it is unknown).

In most cases, the CPT sounding can be achieved relatively quickly (within 1 hour per hole) while closing only one traffic lane. The only difficulty associated with the application of CPT is that prior to each sounding the hole location must be carefully determined on the roadway surface, so that the CPT probe will penetrate within a few feet of the culvert structure. The CPT hole can be positioned with confidence when the height of cover over the culvert is less than 10 ft (3.05 m). The positioning of the sounding location becomes increasingly more challenging as the height of cover increases beyond 10 ft (3.05 m). It is recommended that a modern survey technique or GPS technology be applied to place the sounding holes when the height of soil cover exceeds 20 ft (6.10 m). Additional research work is needed to establish a set of data that can be used to correlate the CPT tip resistance readings and the relative compaction (or dry unit weight) for each type of commonly used backfill materials.

ORITE • 114 Stocker Center • Athens, Ohio 45701-2979 • 740-593-2476
Fax: 740-593-0625 •orite@bobcat.ent.ohiou.edu •http://webce.ent.ohiou.edu//orite/