AN ASSET MANAGEMENT APPROACH FOR DRAINAGE INFRASTRUCTURE AND CULVERTS

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16. Abstract

Drainage infrastructure systems (culvert, storm sewer, outfall and related drainage elements) are mostly buried underground and are in need of special attention in terms of proactive/preventive asset management strategy. Drainage infrastructure systems represent an integral portion of roadway assets that routinely require inspection, maintenance, repair and renewal. Further challenges are the wide geospatial distribution of these infrastructure assets and environmental exposure. There has been considerable research conducted on culverts, but mostly looked at the problem from a traditional structural/geotechnical perspective. Asset management procedures for culverts and drainage infrastructure systems are complex issues, and can benefit a great deal from an optimal asset management program that draws from programs pertaining to buried pipes. The first and most important step in an asset management initiative is the establishment of mechanism for asset inventory and asset conditions in a format compatible with the routine procedures of field operators and inspectors. The first objective of this research project was to develop field protocols and operational business rules for inventory data collection and management and inspection of drainage infrastructures in terms of types of data to be collected, frequency of inspection, and analysis and reporting mechanisms. After review of these protocols by the project oversight committee, a pilot study was conducted to verify efficiency of their implementation. The condition assessment protocol introduced is useful in evaluating the overall condition of culverts and can be used for decision making regarding the repair, renewal or replacement of culverts. For the second objective of this project, investigators examined the inventory and inspection protocols employed by Ohio Department of Transportation (ODOT) and developed a decision support platform, which establishes a link between the inspection results and appropriate repair, renewal and replacement procedures. After applying the recommended procedures, the transportation agencies can better track the conditions of culverts thereby reducing the risks of culvert failures.

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INTRODUCTION

The infrastructure of the nation is a public's asset. The United States has approximately 4,000,000 miles (6,437,376 kilometers) of roadway, making it the largest in the world with millions of culverts hidden underneath. As the philosophical saying, "out of sight is out of mind," there has been more attention and maintenance work for above-ground infrastructure, while the underground infrastructure is failing due to lack of maintenance and proper asset management practices. The underground infrastructure addressed in this project consists of pipes, culverts, and drainage structures, which were constructed several decades ago by various state Departments of Transportations (DOTs) and government agencies. Most DOTs currently do not have proper protocols to identify location, investigate condition and maintain these underground assets. Some recent culverts failures in Michigan, North Carolina, California, Utah, and so on, are examples of the seriousness of culvert asset management problems.

This project focuses on culverts and drainage structures, and develops a model for culvert inventory and inspection. The model consists of a framework that includes strategies and guidelines on how these hidden assets can be tracked and maintained. The Condition Assessment Protocol evaluates the overall condition of the culvert and drainage structures to provide a base for culvert renewal decision-making process. By implementing an effective condition assessment, government agencies can make proper decisions on whether to repair, rehabilitate (renew) or replace deteriorated culverts. After the culvert renewal, the agencies need to continue the recommended asset management process by periodic inspections.

As a part of this project, investigators also examined the inventory and inspection procedures employed in Ohio. The recently published Ohio Culvert Management Manual is addressed. Different repair, renewal and replacement methods employed for culverts are studied and connected to the inspection results through a decision support platform.

BACKGROUND

This project was funded by the Midwest Regional University Transportation Research Center (MRUTC) at the University of Wisconsin – Madison, the Michigan Department of Transportation (MDOT) and the Ohio Department of Transportation (ODOT). The Principal Contractor was Michigan State University. The Center for Underground Infrastructure Research & Education (CUIRE) at The University of Texas at Arlington and the University of Cincinnati were subcontractors to this project.

PROCESS

The literature search for this project was conducted through major civil engineering publications and databases such as American Society of Civil Engineers (ASCE) database, The Engineering Village, Federal Highway Administration (FHWA), Transportation Research Board Records (TRB), American Association of State Highway and Transportation Officials (AASHTO) and the National Cooperative Highway Research Program (NCHRP). A survey of North American (U.S. and Canada) transportation agencies was conducted to obtain information on current culvert practices and future asset management plans. The original duration for this research project was 12 months and due to contractual issues was extended to 36 months.

SURVEY OF TRANSPORTATION AGENCIES

In order to evaluate the current state-of-practice, in summer 2006, a North American survey of the state DOTs was conducted. This survey received an overall response rate of 70%. Eighty one percent (81%) of the respondents said that their culverts were in good condition, six percent (6%) reported very good condition, and thirteen percent (13%) felt that their culverts had reached the end of their useful service life. Majority of the respondents felt that they need some type of asset management protocols to track and assess condition of their culverts. A summary of survey results is as follows:

- Sixty two percent (62%), responded that they had some form of tracking system (for culvert opening more than 3 ft); and twenty four percent (24%) responded that they had no tracking system.

- Thirty two percent (32%) of DOTs responded that they had some procedures to define culverts (such as a culvert dictionary), and twelve percent (12%) are in the process of developing a culvert dictionary and the remaining did not have such a document.
- Seventy five percent (75%) of transportation agencies had procedures to record culvert failure information, twenty percent (20%) did not have such a procedure, and five percent (5%) were developing culvert failure reporting policies.
- Only Sixty percent (60%) of respondents had decided on a culvert inspection interval of 2-5 years.
- Only Virginia, North Carolina, California, Washington and Ontario (In Canada) had developed culvert inspection guidelines.
- Forty eight percent (48%) of the respondents had some form of inspection guidelines, Forty four percent (44%) did not have inspection guidelines and eight (8%) were developing inspection guidelines.
- Seventy Eight percent (78%) of the inspection guidelines included hydraulic capacity; Seventy Seven (77%) percent had guidelines for cracking; Sixty One (61%) percent had guidelines for soil conditions and Fifty Three (53%) percent had guidelines addressing wall thickness.
- Seventy Eight percent (78%) responded that they had no model to predict the service life of culverts, thirteen percent (13%) of the respondent were developing predictive models, the state of Virginia had developed predictive formulas and Delaware used the Pontis Deterioration Models.
- Sixty percent (60%) of the respondents had a condition assessment process for culverts, ten percent (10%) of the respondents did not have and thirty percent (30%) were developing condition assessment framework for culverts.
- Forty seven percent (47%) of the respondents used point source repair, forty two percent (42%) used grouting, and twenty six percent (26%) used the internal seal method for addressing structural and hydraulic problems.
- Fifty two percent (52%) of the respondents had some kind of tracking and monitoring system for culverts, nineteen percent (19%) were developing them. The State of Virginia used a combination of HTRIS, PONTIS and ORACLE for

managing their culverts, The states of Idaho and Delaware used PONTIS, The state of California used MS ACCESS; Alaska, Indiana, Ohio and Alberta had their own in-house software and Ontario had OBMS in visual basics.

- Eighty three percent (83%) of the respondents did not have a Decision Support System (DSS) for culverts. Thirteen percent (13%) had some kind of DSS and four percent (4%) were in the development stage.
- Thirty percent (30%) of the DOTs responded that culvert asset management was very important; seventeen percent (17%) felt it was important and four percent (4%) did not feel it was important.

INVENTORY PROTOCOL

The inventory model developed for this project is based on a defined coding system. A unique identification number is given to every culvert based on the location of the culvert. The inventory model also consists of other information such as general (surrounding information of the culvert), structural, hydraulic, safety, previous repair and barrel and end characteristics of the culvert.

CONDITION ASSESSMENT PROTOCOL

Condition assessment is used to predict when failure of the culvert or drainage structure is likely to occur in order to develop short and long-term plans for its maintenance. To evaluate performance of culverts, this project describes two condition assessment models, *Basic Condition Assessment* (BCA) and *Advanced Condition Assessment* (ACA). The framework for these models is obtained from inventory protocol, surveys and field studies, and discussions with the DOTs. The basic condition assessment model is useful for general inspection of the culvert. During BCA, culvert components are assigned a condition rating (between zero to five) to determine whether the condition of culvert is critical. Using AHP (Analytical Hierarchical Process), a culvert performance score is calculated, and based on that, the culvert is categorized into three zones: Critical Zone *(Red Zone),* Monitored Zone *(Yellow Zone)* and Satisfactory Zone *(Green Zone).*

Culverts that fall in the Critical Zone (Red Zone) are in danger and are further investigated for "Advanced Condition Assessment (ACA)" to decide on immediate action. The maximum score a culvert can obtain is five (5) and minimum is zero (0). Any culvert with a performance score below 2.5 should be further inspected for identification of specific problems. The complete assessment includes a detailed inspection of the inlet, outlet and the culvert barrel. We conducted several pilot studies to validate proposed protocols.

DECISION SUPPORT PLATFORM

A decision support platform is developed after a review of various repair, renewal and replacement methods employed for culverts. This decision platform is designed to link the inspection results of a culvert (which is performed according to the guidelines in the Ohio Department of Transportation's Culvert Management Manual) with the appropriate actions to be taken in order to reduce problems and eliminate possibility of failures. The decision platform divides culverts into 4 zones with respect to their general appraisal score and degree of repair requirements. Zone 1 is considered to be excellent and zone 4 is considered to be failed or in imminent failure. For the remaining zones, different remedy options are recommended.

RECOMMENDATIONS FOR FURTHER ACTION

The current project explained the factors affecting service life of culverts, and how an effective asset management policy can be initiated. Investigating new applications of innovative methods for culvert repair, renewal, or replacement (such as trenchless technologies) would be the second step to utilize the decision platform developed in this research project. The trenchless technology methods have basically emerged from the municipal buried infrastructure renewal market, and many DOTs have started using them with no clear standard methodology. Let alone, there is a lack of any DOT-centered decision support systems that would integrate life-cycle performance and cost of these promising technologies into existing DOT's asset management programs. Lacking is a comprehensive multi-scale engineering study that would be conducted for decision making at upper management level. Moreover, culverts sometimes present an ecological and hydraulic challenge that needs to be considered whenever a new technology is introduced and such challenges have not been addressed in previous studies. There are questions on hydraulic capacity of the culverts after the renewal technology is used, to consider for 100- and 500-year storms. Therefore, the next phase of this project would be to provide a comprehensive study and decision-making procedures for culvert asset management using trenchless technologies and to cover all the aspects of structural engineering, design guidelines, construction aspects, hydraulic considerations and life-cycle-costs. The renewal solutions for culvert problems will be discussed in another MRUTC research project in which the usage of trenchless technologies will be investigated. The new project will provide a decision support system regarding the best trenchless technology for a particular problem.

CHAPTER 1.0
INTRODUCTION

1.1 Introduction to Culvert Asset Management

The United States of America has the world's biggest transportation network system. The industrial growth during 1950s marked a rapid development in construction of high-speed, high-capacity roadway infrastructure. Today, the United States has 3,981,521 miles of roadway of which 46,726 miles belong to national highway system, 2,318,043 miles are paved roadway and 1,624,207 miles are unpaved roadway, which is the largest in the world.

During the construction of these roadways, billions of culverts were installed under them. As the philosophical saying, "out of sight is out of mind," more importance has been given to preserving the physical infrastructure on the surface like roadway, pavements, bridges, guardrails, etc., than underground infrastructure. Various theories, models, framework and management plans are developed to track, inspect, maintain and repair the surface infrastructure. However, the invisible critical components of culverts have been neglected. The location and condition of these pipes comes to notice only when there is a problem such as settlement or complete failure of a roadway. The deterioration of culvert pipes and other components is a growing problem for transportation agencies. The deterioration of pipes because of their increasing age or change of service conditions such as increasing flow due to changing watershed conditions increases the wear and tear of these pipes. Various structural, hydrological, environmental and economical (lack of proper maintenance) factors, may accelerate the deterioration process.

Drainage infrastructure systems (culverts, storm sewers, outfall and related drainage elements) represent an integral portion of Department of Transportations' assets that routinely require inspection, maintenance, repair and renewal. Failure of these systems is costly for DOTs both directly due to the replacement of the failed system and indirectly due to the time and money and even in some cases lives lost for the users of the highway. Therefore drainage infrastructure systems are in need of special attention in terms of proactive/preventive asset management strategy.

The variety in material types, shapes, backfill materials, types of roads located above and environmental conditions make every single culvert unique in terms of its behavior and durability. There have been many studies in order to identify the key parameters affecting culvert behavior but the success rate in providing standard solutions to the problems remained to be low. Had the culvert behavior been completely understood it would have been much easier to manage the culvert inventory by timely renewal and repair efforts.

Wide geospatial distribution of drainage infrastructure assets further complicates the management of these assets. Therefore, the first and most important step in the culvert asset management procedure should be the establishment of a database consisting of asset inventory and asset condition information. By monitoring this database the department of transportation officials will be able to identify the critical culverts before failure and to take necessary steps in a timely manner to repair, rehabilitate or replace these culverts.

The Nation's infrastructure is the public's asset. Construction of these infrastructures is paid through tolls, utility bills, and special taxes on gasoline, airline tickets and other user fees. The public has a share in the expense of construction and maintenance of these assets. Federal and state agencies fund towards the maintenance of these infrastructures through general tax revenues and other sources. But, the current poor condition of the infrastructure indicates that the investment levels are clearly inadequate (Turner, 1999).

To enhance the understandability and usefulness of the general purpose external financial reports of state and local governments to the citizenry, legislative and oversight bodies, in 1999, the concept of Governmental Accounting and Standards Board (GASB) rule 34 was introduced by the federal government (Hughes 2000). This marked the development in the infrastructure funding area, which intended to ensure that municipalities, the Departments of Transportations (DOTs) and local governments are good managers of the public assets.

The Ohio Department of Transportation has published the "Culvert Management Manual" in December 2003. In this manual, two forms are introduced (see Appendix 7):

- CR-87: Culvert Inventory Report
- CR-86: Culvert Inspection Form

A detailed guideline for filling these reports is provided in this manual. An inventory form is used to record the information on the database whenever a new culvert is constructed. The inspection form is used to assess the current condition of the culvert and update the previous information on the database. Therefore, it can be concluded that ODOT has initiated the establishment of the necessary database in order to have an effective culvert asset management. The value of this database is apparent as it contains very important information in tackling the culvert asset management problems. However majority of the DOTs are unaware of the fact as to what assets they own such as different types of culverts, where these assets are located, in what conditions they exist, how to inspect the conditions of these assets, when these assets should be inspected and maintained and finally who makes the decisions in the repair or renewal of these assets.

This report examines the inventory and inspection procedures developed by ODOT and also develops a model for culvert inventory and inspection which provides an answer for all the above questions. A decision support platform is generated after studying various repair, renewal and replacement procedures which establishes the link between the ODOT inspection procedures and appropriate actions to be taken given the condition of the culvert.

1.2 Objectives and Tasks

The primary objectives of this project are to investigate current practices in culvert asset management procedures and factors affecting culvert performance, to develop inventory and inspection models and to provide a platform for a decision support system for culvert inspection, maintenance, renewal, and asset management.

In order to address objectives following tasks were accomplished

Task 1: Reviewing existing literature for best practices on drainage infrastructure and culvert asset management efforts among the 50 state DOTs and 10 Canadian provinces and developing an optimal classification methodology for MDOT and ODOT inventory.

Task 2: Reviewing various hydraulic, land-use changes and mechanical factors affecting the deterioration of drainage structures and checking the collected information against MDOT and ODOT documented history of failed, repaired, as-built, and replaced drainage structures and culverts.

Task 3: Reviewing the existing inspection, data analysis and reporting methods for drainage structures and study of the modifications to be brought to buried pipes technologies to be implemented on drainage structures and culverts.

Task 4: Developing inventory and inspection protocols and business rules for MDOT and ODOT engineers and field operators.

Task 5: Synthesizing the research findings into a platform for a decision support system for culvert inspection, renewal, maintenance, and asset management. The system will help MDOT and ODOT engineers select the optimal procedures and strategy given drainage structure description and condition and will provide them with risk and life cycle cost analysis.

Task 6: Performing pilot studies in Michigan and Ohio to validate the protocol and decision support platform.

Task 7: Collaborating with MDOT and ODOT engineers to write a section on inventory and inspection to be added to current best practices and business rules manuals.

Task 8: Writing a final report documenting all research findings.

Task 9: Writing several papers and articles to disseminate research results specifically for use of other Midwest states.

Task 10: Offering educational workshops for MDOT and ODOT personnel to present results of this important research.

1.3 Background

Culvert Management Manual (2003) by Ohio Department of Transportation (ODOT) defines culverts as “any structure that conveys water or forms a passageway through an embankment and is designed to support a superimposed earth load or other fill material plus live load with a span, diameter, or multi-cell less than 10 ft (3.1m) when measured parallel to the centerline of the roadway," as shown in Figure 1.1

Figure 1.1: Culvert Structure

Culverts are among the important components of the highway infrastructure. Most of these culverts were installed four to five decades back and have reached their design or service life (Perrin, 2004). For this reason, we need a cost-effective system of tracking and monitoring these assets. Public and road safety is another important reason for regular culvert inspection and maintenance. Many times, culvert failures are sudden and may cause potholes or total failure of the roadway. A few case studies of culvert failure are as follows:

- A culvert failed on I–75 at milepost 227 near Prudenville, Michigan, in 2003. The failure occurred when an elliptical 73"x 55" corrugated metal pipe (CMP) arch, failed due to extensive corrosion of its 50' long section. The estimated age of the pipe was approximately 30 years and the destroyed pipe was replaced with a 72" corrugated metal pipe at a cost of $95,000.

Figure 1.2: Culvert Failure in Muskegon, Michigan

- The failure of a 60" CMP culvert in Muskegon, Michigan as shown in Figure 1.2 caused the street closure for five weeks, shut down of a 48" diameter water transmission line and detour of an 8" diameter waterline. The replacement cost of the culvert was $160,000, which did not include social and economic cost associated with detour and lost time to commerce and residents.

Figure 1.3: 84" Diameter CMP Failure in Maryland

- The failure of a 17 year old 84"diameter CMP culvert in Maryland resulted in the injury of two people, when their car fell into a 20' long by 30' wide by 20' deep sinkhole as shown in the Figure 1.3.

Figure 1.4: Failure of 126" diameter CMP in Charlotte, North Carolina

- The failure of a 20 year old, 126" diameter CMP in Charlotte, North Carolina resulted in a massive sinkhole as shown in Figure 1.4. The cost of replacement was approximately $300,000.

Figure 1.5: Failure of a 30 year old, 96" diameter CMP in Hickory, North Carolina

- The Failure of a 30 year old, 96” diameter CMP in Hickory, North Carolina resulted in the formation of a massive sinkhole as shown in Figure 1.5. The sinkhole affected the safety of US highway 70 and caused conflicts between property owner, city and NCDOT as a liability and responsibility for damages. The cost of repair was $ 1.5 Million.

Figure 1.6: Failure of 30-Year Old CMP in Bakersfield, California

- The failure of a 30 year old CMP in Downtown, Bakersfield, California as shown in Figure 1.6, created lot of problems and precipitated the road crossings by the city. As a result of the following incident, CMP is no longer permitted in California.

Figure 1.7: Failure of a 30-Year Old, 96” CMP in West Bountiful, Utah

- The collapse of a 30 year old, 96” CMP in West Bountiful, Utah, resulted in a large sinkhole, which swallowed a pickup truck and flooded a nearby home as shown in Figure 1.7 (ACPA, 2005)

The above case studies and Table 1.1 indicate that all the failures occurred in Corrugated Metal Pipes (CMP) and were due to aging. Other factors, such as corrosion, overloading (both hydraulic and structural), ground movements, etc., may also contribute to early failures. Some of these culverts had reached the end of their service life and transportation agencies had no inspection programs to monitor or preserve these culverts. The sudden collapse of the culvert structure reflects the major safety risk and disruption to the traffic. The cost of road closure, traffic congestion and detour are added to the emergency cost of the culvert replacement. Such a cost is very significant and is added to the life cycle cost of the culvert. Table 1.1 identifies the emergency costs of failed culverts and how the usage a pipe with a longer life such as concrete during initial installation could have been more cost effective and lasted a longer period (Perrin, 2004).

Table 1.1: Cost of Recent Culvert Failures (Perrin, 2004)

Location	**I-70 E of Vail, Colorado**	**I-480 near Maple heights, Ohio**	**SR-79 Buckeye Lake, Ohio**	**SR 173 Taylorsville, Utah**	**I-70 Eisenhower Tunnel, Colorado**
Pipe Size or Type	66” CMP	60” CMP	30” CMP	81” x 59” Arch CMP	60” CMP
Cost of Replacement	$4,200,000	$384,000	NA	$ 48,000	$45,000
Length	85 – 100’	NA	50’	50’	40’
Time to Replace (days)	49	8	6	5	7
Impacted Annual Average Daily Traffic	20,950	16,760	4,920	19,338	1,257
Detour Delay	120 min	60 min	20 min	20 min	30 min
User Cost	$4,046,000	$3,079,000	$290,000	$693,000	$220,000
Total Cost	$8,246,000	$3,463,000	NA	$741,000	$265,000
Pipe Age (Yrs)	35-60	60	30+	20	30
Number of Replacement (Compared to 100 year design life)	1	1	3	4	2
Total Cost for 100 year Horizon	**$8,046,000**	**$3,463,000**	**NA**	**$2,964,000**	**$530,000**
Estimated Cost to Change to 100 year pipe	$12,000	13,000	NA	$6,200	$4,500
Cost-Benefit Ratio	671	266	NA	478	118

A classical function relating to the age of the pipeline to the failure is denoted by a bathtub curve as shown in Figure 1.8. The early part of the curve shows the infantile failure, which is mainly due to construction and manufacturing problems. Then, the failure rate is generally low. During this period failure may occur due to factors such as excessive loads, which the culvert is not designed for. At the end of their useful life, failure rate of culverts increases exponentially. This curve can be applied to an individual pipe, group of pipes with similar characteristics, or the whole population of a pipe network (Najafi, 2005). At present, most of our culverts and drainage infrastructure are at the end of their useful life, so according to the bathtub curve, the probability of their failure is high. The service life of concrete culverts in general is between 70 to 100 years. Whereas, corrugated metal culverts usually fail due to corrosion of their inverts or exterior of their pipe in less than 20 years. Properly protected metal culverts should have a service life of about 50 years. Plastic and aluminum culverts also have their design service life of about 50 years (USACE, 1997).

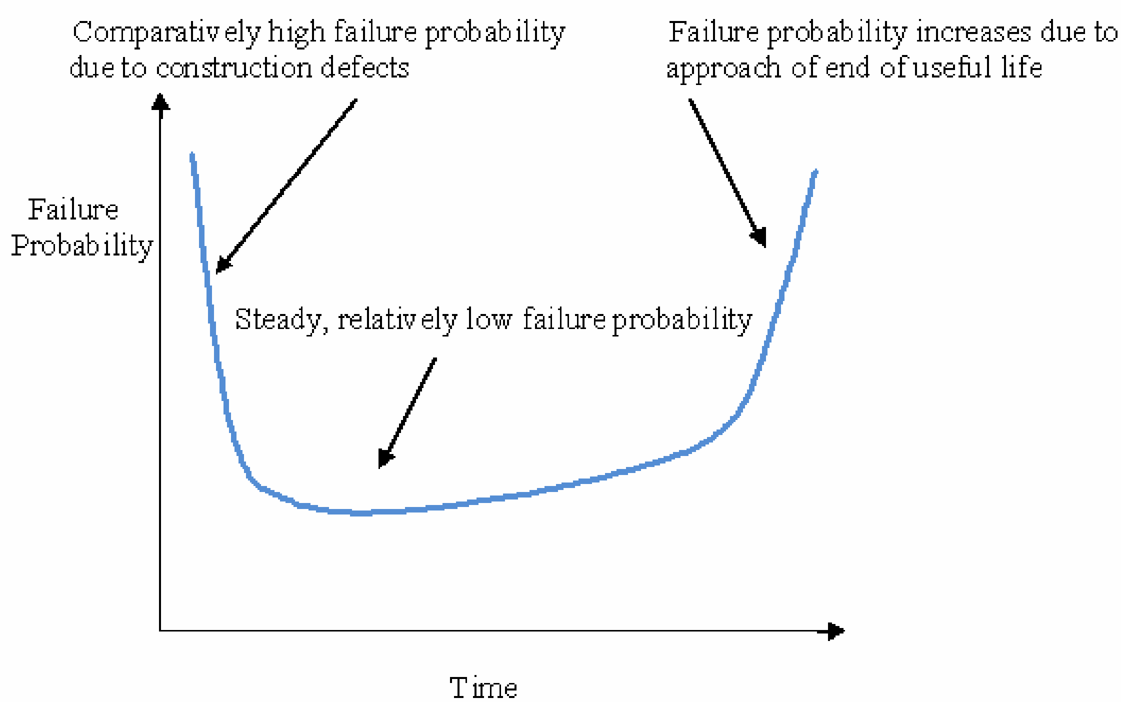


Figure 1.8: Bathtub Curve (Najafi, 2005)

1.4 Preserving the Deteriorating Infrastructure

Governmental Accounting and Standards Board (GASB) is a private, nonprofit organization established in 1984 by Financial Accounting Foundation. GASB establishes concepts and standards that guide the preparation of external financial reports for organizations such as public utilities, municipal hospitals and state universities. In 1999, GASB introduced a concept of external financial reporting for public infrastructure assets known as GASB rule 34. According to the rule, the state and local agencies need not depreciate their assets using the traditional straight-line method every fiscal year. The financial report using traditional method does not intend to measure the actual deterioration, as it may not occur in any given year. Instead, they can follow the Modified Approach, where the financial reports are based on maintaining the assets at a specified condition level. According to GASB-34 rule, infrastructure assets that are a part of a network or subsystem of a network are not required to be depreciated as long as the government can document that the assets are being preserved approximately at (or above) a condition level established and disclosed by the government. GASB 34 recommends depreciation-reporting requirement on infrastructure assets using "Modified Approach," as shown in Figure 1.9.

- Having a current inventory of assets.
- Documenting the condition of those assets, using condition assessment procedure.
- Demonstrating that the assets are being preserved at a determined condition benchmark.
- Estimating the actual cost to maintain and preserve the assets.

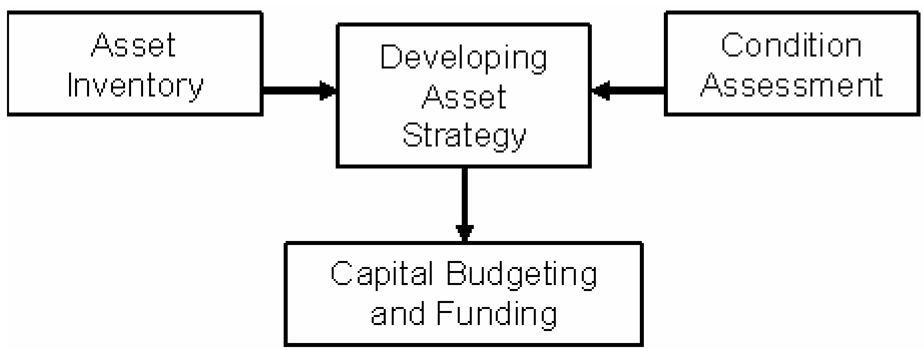


Figure 1.9: Asset Planning Framework – "A Modified Approach"

1.5 Problem Area

Most of the states throughout the country are suffering from heavily deteriorating culverts. The state and local agencies throughout the nation need procedures to evaluate and document their assets using the asset management framework shown in Figure 1.9. The culverts are in need of special attention in terms of proactive or preventive asset management strategies. Most of the research conducted in the past focused on problems from a traditional structural or geotechnical perspective. Although this research improved our knowledge on culvert behavior, it did not focus on methods of operation, routine field inspection, and maintenance aspects. The Michigan Department of Transportation (MDOT) estimates that there are about 200,000 culverts in the state of Michigan. Discussion with MDOT officials revealed that they do not have a set of standard protocols to track these assets and determine their condition. This would significantly increase field problems and sudden failures of these structures, which is a safety and economic issue to the society. The main objective of this research was to develop a framework in the form of protocols for inventory data collection and management plus inspection of culverts using a condition rating system. These protocols were reviewed and then tested in small pilot studies for verification and field efficiency. Another objective of this study was to examine the inventory and inspection procedures developed by Ohio Department of Transportation and develop a decision support platform which establishes the link between inspection procedures and appropriate actions in terms of repair, renewal and replacement of culverts.

1.6 Chapter Summary

The nation’s culverts are deteriorating in response to usage and environmental factors. Preservation of these assets should be undertaken to provide and maintain a serviceable infrastructure. Culvert Preservation seeks to reduce the rate of deterioration and heavy repairing cost due to unexpected failures. The preventive approach is less costly and time consuming than the reactive approach as it is measured by attributes such as quality, safety, and service life (FHWA, 1999). Culvert asset management benefits include (Perrin, 2004):

- Up-to-date inventory
- Reducing failures through inspections
- Reducing emergency repair costs and unplanned financial burden
- Better budget planning for repair and replacement
- Long term ability to identify actual life-cycle and performance of various pipe materials

CHAPTER 2.0

LITERATURE REVIEW

2.1 Introduction

Managing infrastructure is a very challenging task, which requires effective management strategies. Any management strategy requires establishment of the potential degradation of an asset over its life cycle and analysis of the impact of asset failure. Factors such as poor quality control and inadequate inspection and maintenance programs have adversely impacted municipality infrastructures. The rapidly deteriorating culverts demand the local and state agencies to implement an inventory and inspection program. However, predicting and monitoring the condition of pipelines remains as a difficult task (Najafi, 2005).

Culvert inspection and management have been important topics among the present day transportation researchers. The Ohio Research Institute for Transportation and the Environment, at the University of Ohio made an important contribution in their report entitled “Risk Assessment and Update of Inspection Procedures for Culverts,” (Mitchell et al, 2005). They introduced detailed culvert inspection system from data collected at sixty culvert sites. They reported that loss of culvert integrity could result in temporary roadway closure and considerable remediation costs and total collapse of culverts could result in a major safety risk for motorists. The statistical analysis of the culverts indicated that age, rise, flow abrasiveness, pH, flow velocity, and culvert type were significant variables for the rating system. Investigators of this study conducted a national survey about the asset management of culverts in which 40 DOTs responded. According to the results of the survey, 24 DOTs reported that they had an inspection policy for highway culverts. 30 DOTs reported that they did not have a culvert inspection manual whereas only five DOTs did. 23 out of reported that they were using a computer database for the highway culverts in their state. 48% of the respondents specified 1-2 year inspection cycle; and 16% specify a 3-5 year cycle.

Most of the states that inspect culverts have applied a numerical rating system. Five states besides Ohio have developed culvert inspection manuals. Only five other states have developed their own culvert risk assessment procedures. Once the culverts are identified for remedial work in any district, the Adjusted Overall Rating (AOR), which is the average condition rating score adjusted by the culvert age, pH of drainage water, abrasiveness of the drainage flow, and cover height to rise or diameter ratio is used to prioritize the work. The lower the AOR score, the higher the priority for repairs/replacement. None of the culverts examined had serious alignment problems. The service life of concrete culverts appeared to be limited to 70-80 years. The most frequently encountered conditions were deteriorated headwalls, deterioration of concrete in the crown region or top slab and inlet walls, and transverse shear cracks on abutment walls. No serious alignment problems were found at metal culvert sites. No stress cracks were detected at the bolt lines inside any of the metal culverts and the service life of a metal culvert appeared to be limited to 60-65 years. In addition, this report also suggested appropriate renewal techniques depending on structural, hydraulic, and environmental conditions of the culvert

National Cooperative Highway Research Program (NCHRP), Synthesis 303 Assessment and Renewal of Existing Culverts (NCHRP, 2002) performed another important study. The objective of this study was to determine the state of practice of pipe assessment, the selection of appropriate repair or renewal methods, and the management aspects of the pipe program. The study collected information on the state of practice for plastic, concrete, and metal pipes and their appurtenances, such as inlets, outlets, joints, access holes, junction boxes, wingwalls, endwalls, and headwalls. A national survey was conducted focusing on agencies inspection programs, maintenance programs, record keeping, material specifications, service life predictions, management systems, and guidelines for assessment, repair, and renewal.

Most of the transportation agencies surveyed did not have methods to select the best type of pipe repair given the circumstances. In addition, local agencies use their respective state DOTs charts and specifications for renewal and guidelines for assessment if they pursue a pipe management system. The study suggested that the establishment of a preventive maintenance program would help transportation agencies manage the pipes in the system. The data collected from these assessments could be stored in a centralized pipe database, so that users would have access to the data for decision making.

Pantelias (2005) identified the relationship between asset management data collection and the decision processes to be supported by them. Data collection, data management and data integration are the essential steps in order to have an effective asset management framework. Data collection consists of gathering all the necessary information useful in making decisions and can be categorized in three groups listed below:

- **Location** – Actual location of the asset as denoted using a linear referencing system or GPR coordinates.
- **Physical Attributes** – Description of the considered assets that can include: material type, size, length, etc.
- **Condition** – Condition assessment can be different from one asset to another according to set performance criteria. The data can be qualitative and generic (e.g. good, bad, etc.) or detailed and/or quantitative in accordance to established practices and standards (e.g. condition or performance index).

Another survey conducted by Perrin Jr. and Jhaveri (2004) points out that 4 out of 25 responding agencies were using a least cost analysis for pipe material selection and 2 out of 25 agencies were incorporating the risk of failure during their cost analysis.

2.2 GASB – 34

Governmental Accounting and Standards Board – Rule 34 highlighted the importance of asset management in preserving the infrastructure. GASB – 34 “establishes methods for governments to be more accountable to bond market analysts and underwriters, citizens, and other financial users. The potential impact of GASB – 34 extends beyond financial reporting statements and may influence the manner in which infrastructure is thought of by citizens, legislators, and others interested in public finance and infrastructure performance” (FHWA, 2000).

The state and local agencies have to record all their capital and infrastructure assets and investments separately and submit it to the federal agencies at the end of every fiscal year. As most of the infrastructures deteriorate with usage, aging and environmental effects, the agencies can choose to determine their value either by depreciating them using the straight line depreciation method or by using the modified approach. In modified approach: “Infrastructure assets are not required to be depreciated if 1) the government manages those assets using an asset management system that has certain characteristics and 2) the government can document that the assets are being preserved approximately at (or above) a condition level established and disclosed by the government. Qualifying governments will make disclosures about infrastructure assets in required supplementary information (RSI), including the physical condition of the assets and the amounts spent to maintain and preserve them over time” (GASB, 1999).

2.3 Asset Management

Asset management is a way of doing business. It is a tool used by both public and private entities to manage their assets so that they meet business and customer needs at the lowest possible cost over the longest possible period. Asset management means getting the right information to the right people, at the right time, to obtain the right decision.

Various asset management definitions are (FHWA, 1999):

“A methodology needed by those who are responsible for efficiently allocating generally insufficient funds amongst valid and competing needs.”

- *The American Public Works Association Asset Management Task Force*

“A comprehensive and structured approach to the long term management of assets as tools for the efficient and effective delivery of community benefits.”

- *Strategy for improving asset management practice, (AUSTROADS, 1997)*

“Asset Management ... goes beyond the traditional management practice of examining singular systems within the road networks, i.e., pavements, bridges, etc, and looks at the universal system of a network of roads and all its components to allow comprehensive management of limited resources. Through proper asset management, government can improve program and infrastructure quality, increase information accessibility and use, enhance and sharpen decision making, make more effective investments and decrease overall costs, including the social and economic impacts of road crashes.”

- *Organization for European Cooperation and Development Working Group, Asset Management Systems, Project Description, 1999*

2.4 Goals and Principles of Asset Management (NCHRP, 2002)

Asset management incorporates multiple business processes to meet the following goals:

- To build, preserve, and operate facilities more cost effectively with improved performance
- To deliver agency's customers the best value for the tax dollars spent
- To enhance the creditability and accountability of the agency to the legislature and the public

The key principle of asset management is that a department can look at its existing procedures and see how better decisions on infrastructure management can be made with better information. The core principles for customer focused, mission driven, and system oriented asset management processes are:

- It is a strategic approach to manage the infrastructure.
- It encourages decision making that considers a broad range of assets and is driven by policy goals and objectives.
- Good asset management process must rely on quality information and good analytic capabilities.
- It is proactive – asset management decision making process encourages preventive strategies rather than the reactive "worst-first" approach (NCHRP 2002).

2.5 Asset Management Framework and Strategy (FHWA, 2000)

An asset management system has the following major elements, which are constrained by available budgets and resource allocations:

- Establishment of goals and policies
- Data collection and development of asset inventory
- Establishment of performance measures leading to condition assessment and performance modeling
- Development of management systems to evaluate alternatives and control optimization
- Decision making regarding short and long term project selection
- Implementation of designed programs and evaluation process
- Use of evaluation results for overall process feedback, redevelopment or refinement

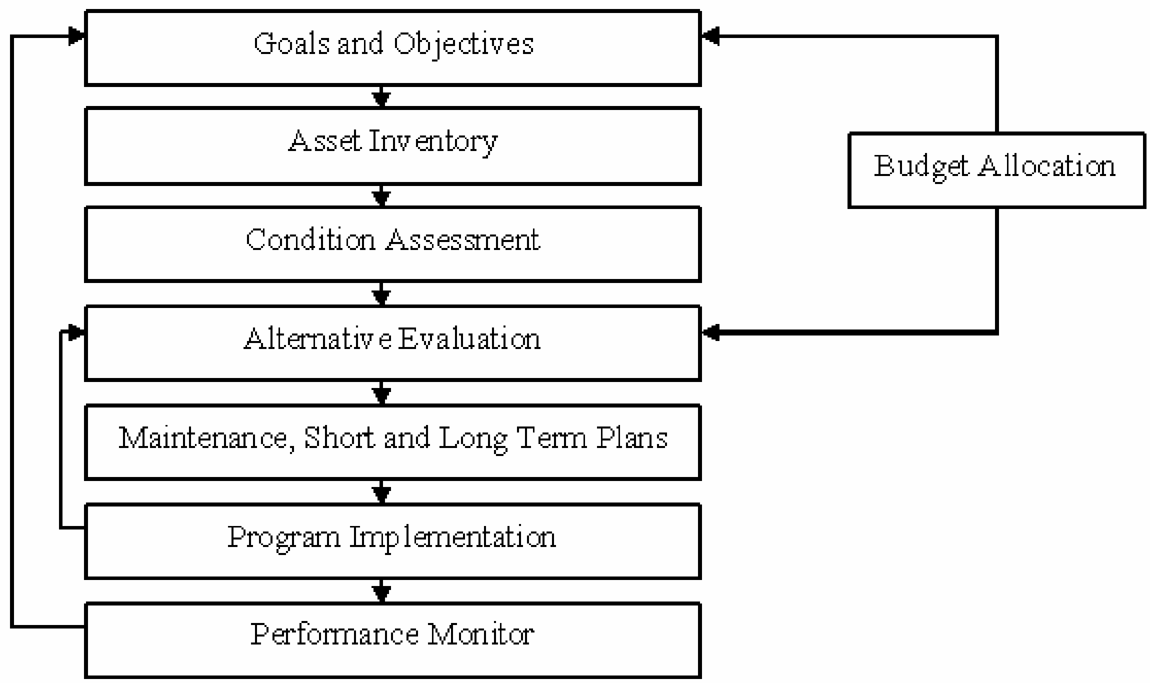


Figure 2.1: Generic Asset Management Framework

This asset management framework helps in responding to the GASB 34 requirements and explaining the financial accountability to the public. It also assists the transportation agencies in complying with the requirements of "modified approach." Therefore, asset management results in better cost effective decisions, and improves a states ability to set system condition and performance targets, and to meet them through effective decision-making.

An asset management strategy focuses on maintenance practices associated with the component and the function of that asset. The ingredients of the strategy attempts to answer the questions listed in Table 2.1 (FHWA, 2000).

Table 2.1: Ingredients of Asset management Components (Hughes, 2000)

What do you own?	Asset identification and complete inventory of all assets
What is it worth?	Complete financial data
What is its condition?	Physical description data including operational performance data, condition monitoring, and maintenance backlog

What is the remaining service life?	Estimation of useful physical and economic life of the assets
What is the maintenance strategy?	Operational procedures, preventive or predictive and condition based maintenance schedules
Other current practices?	Decision support methods in use for repair or replacement decisions for assets
What is the replacement strategy?	Estimated replacement that is ahead of useful physical or economic life of the asset
What level of service need to be provided?	includes minimum performance and service standards
What are the existing and future performance demands?	Estimation of projected population growth, consumer usage trends, etc

2.6 Culvert Asset Management

Culvert asset management provides the ability to show how, when, and why culvert resources were or are committed. Transportation officials are highly accountable for all transportation assets. The DOTs, by monitoring the culverts and knowing their condition will benefit from lower culvert repair cost from reducing failure. The traveling public will benefit from culvert asset management because user delays are minimized. As sinkholes in roadways have been increasing over the past years, this is quite a concern. The cost of inspecting and maintaining culverts is an added economic burden to the state and local agencies. An asset management approach would result in cost saving over the emergency repair of culvert failures which is an increasing problem in the nation. Asset management practices improve efficiency and increase the value of services to transportation users.

Some of the benefits to DOTs from asset management practices are (Perrin, 2004),

- Accountability to the public
- Increased budget demands
- Rational approach to resource allocation
- Defense against politicizing the program

The American Association of State Highway and Transportation Officials (AASHTO) and Federal Highway Association (FHWA) recommend that asset management is a better way to do business. They provide national leadership and guidance to states for implementing and developing asset management in all states (Perrin, 2004). The culvert management system allows the transportation agency to have an inventory of culverts, and to develop a short and long-term plan for maintenance and renewal (FHWA, 2001).

2.7 Culverts (Engineering Consideration)

The American Association of State Highway and Transportation officials (AASHTO) defines culvert as (AASHTO, 1999),

- A structure which is usually designed hydraulically to take advantage of submerges to increase hydraulic capacity
- A structure used to convey surface runoff through embankments
- A structure, as distinguished from bridges, which is usually covered with embankment and is composed of structural material around the entire perimeter, although some are supported on spread footing with the streambed serving as the bottom of the culvert

2.8 Hydrology

Hydrology is the science that deals with occurrence and distribution of water on the earth. In designing culverts, it is the process of determining how much flow the culvert should be designed to carry.

- Hydraulic cycle – this is the name given to the cycle of water in the atmosphere falling to the ground, running off to rivers, lakes, and the ocean and then evaporating back to the atmosphere

- Peak Flow – peak flow refers to the maximum amount of water that will arrive and flow past a particular part of land. The peak flow is a major factor in the culvert design process. This value depends upon many topographic, geological, and environmental factors such as:
  - The size, shape and slope of drainage area
  - The rainfall intensity, storm duration, and rainfall distribution within the drainage area
  - Type of land use (open ground, paved, wooded, etc.)
  - The type of soil and its degree of saturation or imperviousness
  - Type of precipitation and ambient temperature
  - Existing flow if stream is present

2.9 Hydraulics

Culvert hydraulics deals with the consideration and analysis of factors that influence its carrying capacity. The factors include headwater depth, tailwater depth, inlet geometry, slope, and roughness of culvert barrel. All these factors can be grouped into two conditions:

- Inlet Control
- Outlet Control

Inlet Control - When a culvert functions under the inlet control or entrance control, the flow through the culvert and the associated headwater depth upstream of the structure are primary functions of the culvert entrance. As the headwater depth increases, it forces the discharge through the culverts. The entrance capacity is determined by opening area, shape of the opening, and inlet configuration. Under inlet control, the culvert never flows full through its entire length and the design must balance the peak flow to the culvert location against the allowable depth and the spread of backwater. Possible changes in land use and runoff rates must be given consideration.

Figure 2.2: Culverts functioning as Inlet Control
(Source: Hydrocad Storm Water Modeling, 2008)

Outlet Control – A culvert functions under outlet control when it is not capable of conveying as much flow as the inlet is accepting. The discharge is influenced by the same characteristics as inlet control plus the tailwater depth and barrel characteristics like slope, length and roughness. The flow is usually subcritical or under pressure through the structure. While designing outlet control, downstream protection must be considered against scouring or erosion.

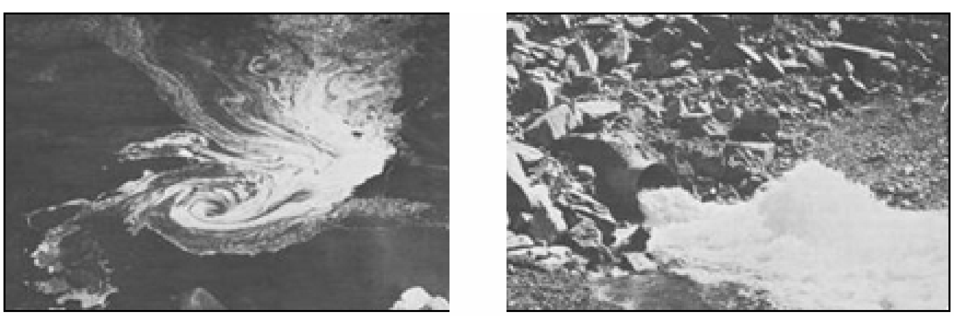


Figure 2.3: Culverts functioning as Outlet Control
(Source**:** Hydrocad Storm Water Modeling, 2008)

Table 2.2: Comparisons between Inlet and Outlet Control
(Source: Haested Methods, 2006)

Inlet Control	Outlet Control
Design discharge (Q) is a function of inlet geometry	Design discharge (Q) is a function of outlet geometry
Inlet capacity is less than barrel capacity	Inlet capacity is greater than barrel capacity
Barrel does not flow full	Barrel can flow full
Culverts act as an orifice or weir	Culverts act as a pressure conduit
Normal depth is less than critical depth	Normal depth is greater than critical depth
Culvert slope is greater than critical slope	Culvert slope is less than critical slope
No influence on headwater elevation by water surface elevation at culvert exit	Water surface elevation at culvert exit is an important factor in calculating headwater elevation

2.10 Types of Flow (FHWA, 2001)

Full Flow **–** The hydraulic condition where the culvert is flowing full is called pressure flow. The back pressure caused by a high downstream water surface elevation causes the pressure flow condition. The capacity of the culvert operating under pressure flow is affected by upstream and downstream conditions and by the hydraulic characteristics of the culvert.

Figure 2.4: Culvert Flowing under Pressure Flow
(Source: Eatonvillenews.net, 2008)

Free Flow – Free flow is also called an open channel flow and is characterized as subcritical, critical, or supercritical. The flow regime is determined by evaluating a dimensionless number called Froude's number as shown below:

$$F_r = \frac{V}{(g.y_h)^{1/2}}$$

Where,

F_r = Froude number — y_h = Hydraulic depth

V = Average velocity of flow — g = Gravitational acceleration

If F_r >1.0, then the flow is supercritical and is characterized as swift flow

If F_r <1.0, then the flow is subcritical and is smooth.

If F_r = 1.0, then the flow is critical

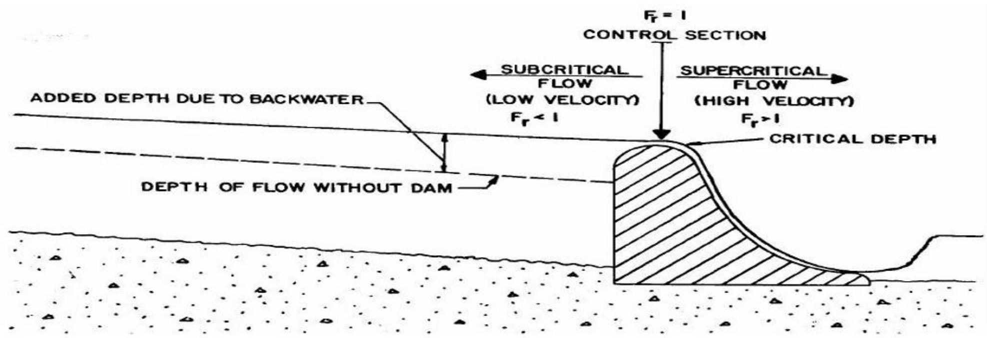


Figure 2.5: Flow Conditions for a Small Dam (Source: FHWA, 2001)

The same flow conditions as shown in Figure 2.5 occur in case of a partially full steep culvert. The critical depth would occur at the culvert inlet, subcritical flow could exist in the upstream channel, and supercritical flow would exist in the culvert barrel, as shown in Figure 2.6.

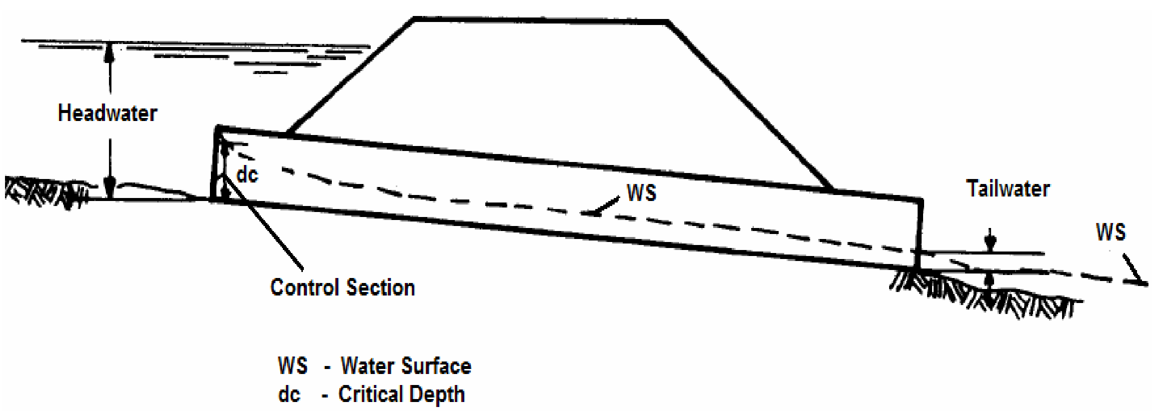


Figure 2.6: Typical Flow in a Partially Full Culvert (Source: FHWA, 2001)

2.11 Structural Aspects (FHWA, 1986)

Flexible Culvert Behavior – A flexible culvert is a composite structure made up of culvert barrel and the surrounding soil. The barrel and the soil are both vital elements to the structural performance of the concrete.

Flexible culverts have less bending stiffness or bending strength on their own. As shown in the Figure 2.7, as vertical loads are applied a flexible culvert attempts to deflect. The vertical diameter decreases while the horizontal diameter increases. Soil pressures resist the increase in horizontal diameter.

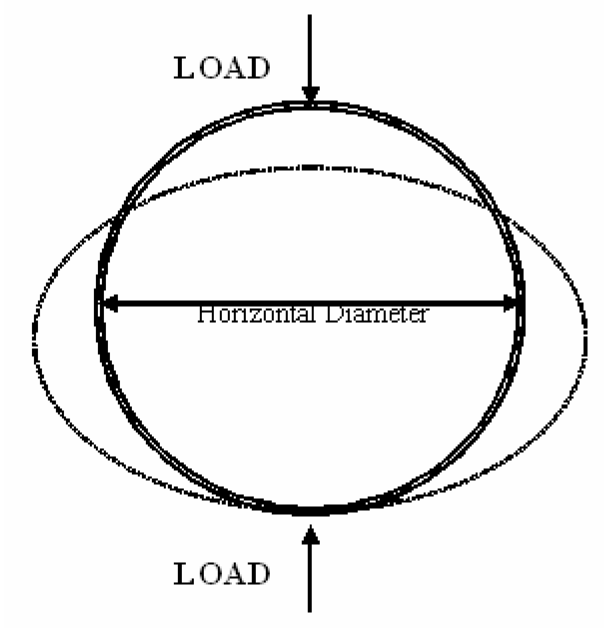


Figure 2.7: Deflection of Flexible Culverts (Source: FHWA, 1986)

When good embankment material is compacted around the culvert, the increase in horizontal diameter of the culvert is resisted by the lateral soil pressure. In circular shaped culverts, a uniform radial pressure is developed around the pipe that creates a compressive thrust in the pipe walls. An arc of a flexible round pipe or other shape will be stable until soil pressure is achieved and resisted by compressive force on each end of the arc. Good quality backfill material and proper installation are critical in obtaining a stable soil envelope around a flexible culvert.

Rigid Culvert Behavior – The load carrying capacity of rigid culverts is provided by the structural strength and from the surrounding earth. When vertical loads are applied to a rigid culvert pipe, zones of tension and compression are created as shown in Figure 2.8. Reinforcing steel is added to the tension zones to increase the tensile strength of concrete pipe. Shear stress in haunch area can be critical for heavily loaded rigid pipe on hard foundations. Since a rigid pipe is stiffer than the surrounding soil, it carries a substantial portion of the load.

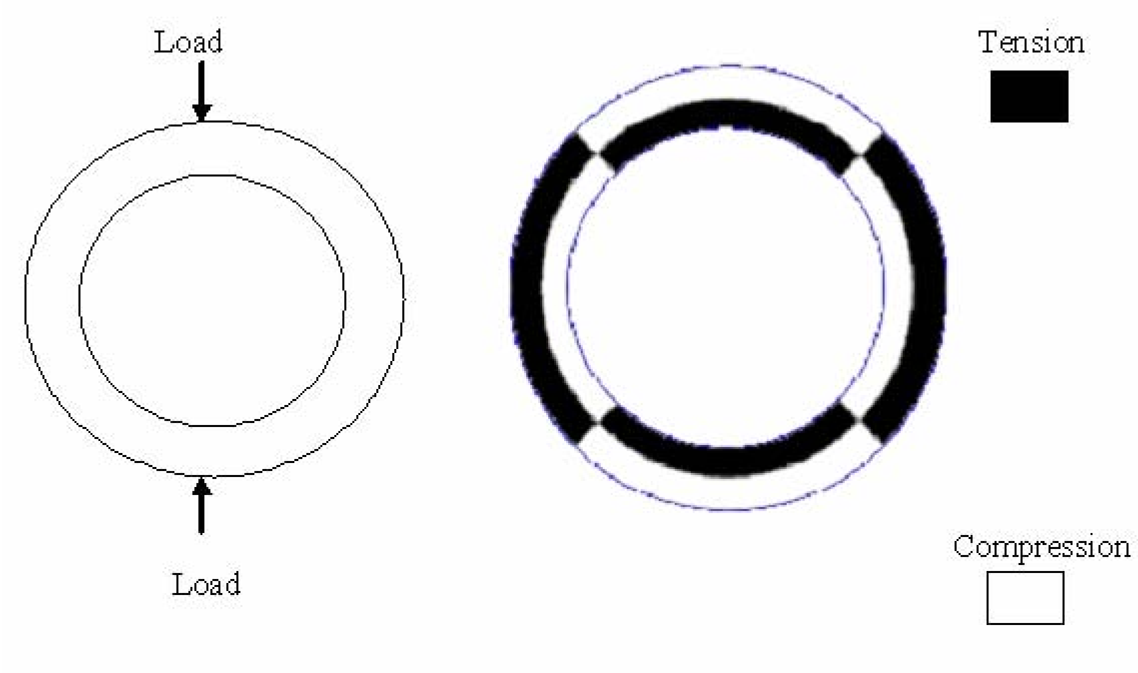


Figure 2.8: Zones of Tension and Compression in Rigid Pipes

2.12 Classification of Culverts

Culverts can be categorized based on their shapes, materials and sizes. The selection of a shape for a culvert depends on depth of cover or headwater elevation, potential for clogging by debris, stream profile, or structural and hydraulic requirements. Culverts can be grouped into the following groups according to the ODOT Culvert Management Manual:

Culvert Types by Material

- Corrugated Metal
  - Coated Corrugated Steel Pipe
  - Coated with Paved Invert Corrugated Steel Pipe
  - Galvanized Corrugated Steel Pipe
  - Corrugated Metal, Pipe
  - Corrugated Metal, Non-sectional Plate
  - Corrugated Metal, Sectional Plate
  - Corrugated Stainless Steel, Non-sectional Plate
  - Corrugated Stainless Steel, Sectional Plate
  - Corrugated Aluminum Alloy
  - Steel Casing
  - Corrugated Steel Spiral Rib
  - Cast Iron or Ductile Iron

- Aluminum
    - Corrugated Aluminum Spiral Rib

- Plastic
    - Corrugated Plastic
    - Polyvinyl Chloride
    - High Density Polyethylene Liner

- Concrete
    - Plain or Reinforced Concrete
    - Corrugated Plastic Smooth Interior

- Masonry
    - Field Tile (Clay)
    - Vitrified Clay
    - Brick
    - Timber
    - Stone

Culvert Types by Shape

- Circular
- Elliptical - Horizontal
- Elliptical - Vertical
- Pipe Arch
- Pipe Arch, Sect. Plate
- Arch
- Box Culvert
- Slab Top Culvert

Protection types

- Unprotected
- Galvanized
- Half Bituminous Coated
- Fully Bituminous Coated
- Half Bituminous Coated and Paved
- Fully Bituminous Coated and Paved
- Asbestos Bond Coated
- Asbestos Bond Coated and Paved
- Vitrified Lined
- Field Paved
- Coal Tar Resin
- Thermoplastic Coated
- Aluminum Coated

2.12.1 Culvert Types by Materials

Culverts are constructed of concrete, metal, masonry, timber, clay, and plastic material. The strength and physical characteristics of the materials depends upon their chemistry and the interrelationship between the constituent materials. Metals and plastic are homogeneous and isotropic materials, whereas concrete and masonry are a mixture or combination of materials. The method by which the materials are connected significantly influences whether the strength of the materials may be utilized structurally.

Corrugated Metal Culverts

Corrugated metal culverts have been in service for more than 60 years in the U.S., along with concrete culverts. Variety of shapes and sizes available, and ability of modification to increase the durability of the culvert has made this material preferable in many sites. According to Ring (1984), Kent Allemeier, Chairman of Technical Section for AASHTO Subcommittee on Materials, the following are advantages of Corrugated Metal Pipe:

- They are ideal for shipping due to their lightweight
- Their sizes and shapes vary in a large range
- The thickness of the sheets and also the corrugations can be selected from a wide range in order to obtain the required strength
- Easy for the working crew to assemble and install

Also, the disadvantages of Corrugated Steel Pipe are as follows

- Corrugation roughness decreases the rate of flow except for the smooth – line pipes
- Due to presence of sand and/or rock in a high velocity stream, abrasion may cause loss of metal
- High sensitivity to high or low soil pH or water pH, and soil or water resistivity, which may end up with corrosion
- Backfill operations must be handled with care due to the importance of soil support for load bearing

The most important factors affecting durability of Corrugated Metal Pipes are pH, dissolved salts, hardness, alkalinity, abrasiveness, and time of water contact. The rate of corrosion of CMP is affected negatively as the difference between acidity and chloride/sulfate salts and hardness and alkalinity salts increase with presence of abrasion. Usually the rate of waterside corrosion is more rapid than the soil side corrosion therefore controlling factor is water side corrosion but not the soil side corrosion. (Bednar, 1989) Apart from abrasion and corrosion, corrugated metal pipes are also affected by backfill operations. Improper choices of backfill material selection, presence of ground water, and level of compaction equipment have very significant effects on structural performance of CMP (Sehn, 1994).

Several different protective coatings have been applied to the invert sections of the corrugated metal pipes where abrasion and corrosion was considered as a problem. Some of the studies investigating the durability and structural problems of corrugated metal culverts and the coating types are discussed in the following section:

One of the most thorough studies related to the durability of culverts is the "Ohio Culvert Durability" (Meacham et al, 1982). In this particular project, 1616 culverts were inspected in total which consisted of reinforced concrete pipes and galvanized corrugated steel pipes. The number 1616 was reached by taking twenty percent of the total number of culverts with a diameter of 42" and higher gathered in the inventory database created in 1971. According to the decided breakdown of structures to be inspected 67% of the 1616 culverts were metal and 33% concrete. Percentage of the metal culverts was higher than the percentage of the concrete culverts due to their higher variety. Corrugated metal culverts involved structural plate pipes and corrugated metal pipes. Selection of the culverts to be inspected also involved an age criteria, making the sample equally divided between 10 years of intervals. Table 2.3 summarizes the total number of culverts in the inventory and the number of culverts inspected.

Table 2.3: Breakdown of Culverts Inspected (Meacham et al, 1982)

Material Type	Inventory	Inspected	% Inspected
Concrete	4170	545	13
Corrugated Metal	2193	685	31
Sectional Plate	1600	386	24
Total	7963	1616	20

A visual rating system was used in order to evaluate the conditions of the culverts. This system used 5 different classifications namely, Excellent, very good, good, fair and poor.

According to the statistical analysis conducted by authors, the biggest factor affecting the metal culvert rating was found out to be the age of the culvert which was defined as the time in years that the metal itself was exposed to the flow. Other significant parameters were determined as the pH of the water and abrasion. The acidity of the flow was shown to have a negative impact on the culvert condition. Abrasion was found to be detrimental for the flows with high pH flows. Four different equations were provided relating these significant variables to the metal loss for corrugated metal pipes with and without abrasion and for structural plates with and without abrasion respectively. Those equations yielded R-squared values in the range of 0.694 to 0.815.

Conventional Bituminous Protection was also analyzed in this study. Bituminous protection was divided into two groups: First one, was the bituminous coating, second one was the bituminous coating with paved inverts. For the bituminous coating age was found to be the only factor with a statistically significant effect. The correlation between the age and protection rating was too low to reach to a conclusion about the service life of the protection. Therefore authors followed another strategy, which involved performing regression analysis to the protection rating and to the percent of culverts rated as "not poor". This strategy yielded a good correlation and the service life was estimated at 3.16 years. For the bituminous coating with paved invert type of protection, age (very large negative effect), sum of sediment depth and flow depth (large negative effect) and abrasion (minor negative effect) was shown to have statistically significant effects. Correlation coefficient was found to be somewhat bigger than the bituminous coating but again it was not enough to reach a conclusion about the service life. The same strategy was used for the bituminous coating with paved invert type of protection and this strategy yielded 25 years of service life for the case where dry weather flow was within the paved section and 12 years of service life where dry weather flow overtopped the paved portion. Authors highlighted the difference between these two values and reached to the conclusion that the level of dry weather flow played a very important role on the service life of this particular protection.

A similar study is recently completed in May 2005 by Ohio Research Institute for Transportation and Environment (Mitchell et al, 2005). In this study authors inspected a total number of 60 culverts with the objectives of verifying and modifying the inspection procedures of Ohio Culvert Management Manual and determining the significant parameters for culvert durability. The breakdown of these 60 culverts was decided as 25 concrete culverts, 25 metal culverts and 10 thermoplastic culverts. Some of the characteristics of the 25 metal culverts are listed in Table 2.4.

Table 2.4: Properties of Corrugated Metal Culverts Studied in Ohio

Description	Reading	Characteristics
Shape	7 out of 25	pipe-arch
	18 out of 25	circular
Age	14 out of 25	25 to 50 years old
	3 out of 25	50 to 75 years old
	8 out of 25	unknown
Span	7 out of 25	2 to 5 ft.
	14 out of 25	5 to 8 ft. span
	4 out of 25	larger than 8 ft span
Soil Cover	11 out of 25	0 to 5 ft
	5 out of 25	5 to 10 ft
	3 out of 25	10 to 20 ft
	1 out of 25	10 to 20 ft
	5 out of 25	more than 30 ft
Road Type	4 out of 25	interstate
	1 out of 25	U.S. Highway
	20 out of 25	State Highway
Annual Daily Traffic	3 out of 25	less than 1000
	11 out of 25	1000 to 4000
	5 out of 25	4000 to 10000
	3 out of 25	10000 to 30000
	3 out of 25	more than 30000

Description	Reading	Characteristics
pH	2 out of 25	less than 6
	22 out of 25	6 to 8
	1 out of 25	more than 8
Abrasiveness	12 out of 25	abrasive
	13 out of 25	not abrasive

According to the results of the inspections, the authors determined the maximum service life of metal culverts as 60 to 65 years and they have showed that culvert type (whether a corrugated metal pipe or a structural steel plate), pH, abrasiveness, flow velocity, age and rise were the significant parameters which affected the culvert rating. Authors observed that perforation at the invert and the flow line, scour at the inlet and outlet and concrete headwall movement were the most frequently encountered problems whereas culvert alignment was not a problem in most of the metal culvert sites and stress cracks were not observed at the bolt lines of any of the metal culverts. According to the authors the invert region was more sensitive to material deterioration compared to other regions. However, crown corrosion can also be a problem for some metal culverts due to the seepage of groundwater containing road salts. Hurd and Sargand (1988) pointed out the crown corrosion on metal culverts after examining 10 corrugated steel rib stiffened box culverts.

Degler et al (1988) conducted another major study related to the structural plate corrugated metal pipe structures of the arch-pipe configuration. This is an important study because the authors indicate that at the time of study approximately half of the structural plate corrugate metal pipes in Ohio were of pipe-arch configuration and all 12 districts of Ohio were involved in the study, therefore the resulting number of pipes inspected was as high as 890. According to the statistical analysis of the field data conducted by the authors, the durability of the structure was found to have a linear relationship up to 35 years and after 35 years the deterioration rate was found to be increasing. The durability of the corrugated metal structures was determined to be affected by the presence of high abrasive streams and low pH values in the Southeastern Ohio. The most frequently mode of failure encountered by the authors was corrosion and pitting of the multiplate structure, and seepage and corrosion of the bolted joints.

Bituminous coating was examined in the "Ohio Culvert Durability" study and it was given as a summary in this report. Following section gives more information on other types of protective coatings:

Hurd (1984) investigated the protective linings in Ohio in his paper, "Field Performance of Protective Linings for Concrete and Corrugated Steel Pipe Culverts." Epoxy-coated concrete pipe, polymeric-coated corrugated steel pipe, and asbestos bonded bituminous coated and paved corrugated steel pipes located at the corrosive and abrasive sites of Ohio, Indiana and Kentucky were monitored. Number of polymeric-coated pipes monitored was 57, and number of asbestos-bonded bituminous-coated and paved culverts was 38. The major factor affecting the durability of the polymeric coating was determined as abrasiveness. The pH of the flow was not found to be effective on the coating; however it was found that it had an adverse effect on the pipe where the coating was worn away by the abrasive flow. Polymeric coating was found to be satisfactory at low pH sites with nonabrasive flow. Asbestos bonding was also found out to be affected by the abrasiveness. The adherence of bituminous coating was observed to be increasing with the presence of asbestos bonding. Asbestos-bonded bituminous coating with invert paving was shown to provide satisfactory results at low pH sites, with up to moderate abrasiveness.

Pyskadlo and Renfrew (1984) investigated the polymer coating for corrugated steel pipes in New York. Their findings support the study of Hurd. Abrasiveness was found to affect the durability of the polymeric coating therefore authors suggested using a stilling basin to increase the durability of the polymeric coating. Renfrew (1984) further investigated the durability of Asphalt Coating and Paving on Corrugated Steel Culverts in New York. According to his findings round pipes had better coating durability than the arches and the coating on the round pipes added 30 years of life whereas the coating on the arches added only 20 years of life to the structure.

Another form of protective measures for steel pipes is using Aluminum instead of Zinc and obtaining an aluminized steel pipe. Morris and Bednar investigated the performance of aluminized steel and compared it to the galvanized steel at 54 test sites. According to the results of their investigation aluminized steel was found to show a significantly better performance compared galvanized steel in terms of corrosion and perforation. Stavros (1984) investigated the combined effect of zinc and aluminum on steel pipe improvement. The combined coating of zinc and aluminum with steel is sold with the trade name of Galvalume. As a result of the tests, Galvalume demonstrated the best performance compared to galvanize and aluminum coated pipes.

Apart from abrasion and corrosion, corrugated metal pipes are also affected by the backfill operations. Improper choice of backfill material selection, presence of groundwater, level of compaction and compaction equipment used have very significant effects on the structural performance of corrugated metal pipes. For example, Sehn and Duncan (1984) investigated a replaced corrugated metal culvert due to excessive deformations. According to their findings, silty soil is found to be significantly affected by the vibratory loading during the compaction of the backfill. The strains were determined to be much higher in vibratory loading. Another example can be found in a study by Cowherd and Corda (1994). In this study data from some of the failed metal culverts were compared with the data from the study of Degler et al Suggestions were made due to the percentage of mid ordinate reduction and depth of cover. Effects of different types of backfill material with different levels of compaction were graphed.

Structural failures of metal culverts may be frequently attributed to corrosion and abrasion related durability problems. However, excessive deflections during the installation and backfilling procedures may pose an important hazard to the structural integrity of the culvert as well.

To sum up, most common problems associated with the corrugated metal culverts are their sensitivity to abrasion and corrosion and improper installation. Abrasion and corrosion may lead to severe durability problems and in some cases these may cause structural failures. Improper installation techniques may lead to severe shape distortions, joint or seam problems and misalignment. Corrosion can be eliminated or at least lessened by using appropriate type of protection. Abrasion can be eliminated by using stilling basins. Structural problems can be eliminated by following the specifications and design guidelines and by proper application on the field.

Concrete Culverts

Concrete is one of the oldest materials used in all types of constructions. As the usage of precast concrete increased, designers started using this material in drainage infrastructure. Being more rigid compared to metal, concrete culverts are more resistant to the backfill loading, corrosion, and abrasion. Ring (1984) quoted the advantages and disadvantages of concrete culverts as follows:

Advantages of concrete culverts:

- Their sizes and shapes vary in large range
- The thickness and strength of the concrete, amount, and configuration of the reinforcement vary in a large range, making it possible to design appropriately for a specific site
- Resistant to corrosion and abrasion in normal installation
- The flow has better characteristics due to the smoother surface compared to corrugations
- Rigidity of concrete makes it better in resisting loadings during compaction

Bealey (1984) explains the effect of different environmental conditions on concrete culverts. Abrasion and erosion, freeze-thaw, sulfate soils, chlorides; and acids are the conditions which are the most important factors that determine the durability of concrete culverts. Acid attack is the only significant harmful attack for precast concrete culverts. The study compares cast-in-place concrete culverts with precast concrete culverts and reaches the conclusion that precast concrete culverts can withstand the most aggressive environments if they are designed accordingly.

Concrete culvert structures usually do not face structural problems due to their rigidity. However, soil conditions adjacent to the concrete pipes can create problems. Heger and Selig (1994) investigated two case studies in rigid pipe installation failures. According to the results of their investigation, soft soil adjacent to the pipe under high fills can cause increased earth loads on the structure. They suggest that soft soils be removed from each side of the culvert for a distance of at least one diameter.

The performance of concrete culverts depends on the pH of the flow, age of the culvert, sediment depth, slope, presence of roadway deicing salts, and soil strata next to the culvert. From the studies, concrete culverts appear to be more durable than metal culverts but they are heavier and installation process is hard. In a study made in the "Ohio Culvert

Durability Study" (Meacham et al, 1982) a total of 545 concrete culverts were inspected and statistical analysis for those inspected culverts was performed. According to the observations and results given in this report, concrete culverts were found to have different behaviors with respect to the different pH levels. For pH larger than 7, the age of the culvert was shown to be the only significant variable where slope, flow velocity and abrasion also showed significant but minor effects on the concrete rating. For water pH smaller than 7 (acidic flow), pH was determined as the highest significant effect. As the acidity increased (pH got smaller), the concrete rating was found to be decreasing with an increasing rate, beyond the pH level of 4.5, protection was suggested for the concrete culverts. Other significant variables were determined as pipe slope, sediment depth (positive) and age (negative). Regression equations relating these significant variables with the concrete rating was found to yield an R-squared value of 0.82.

Some of the protection types for concrete culverts were also inspected during this project. According to the inspections of the authors, vitrified clay liner plates were observed to perform very well in extremely acidic conditions. Concrete field paving, was found to be successful in extending the life of the pipe in acidic conditions however the paving deterioration rate was observed to be faster than the pipe itself. Coal tar pitch coating was applied in some concrete culverts in Ohio. But according to the investigations of the authors it performed poorly and did not last longer than 5 years in any of the sites.

ORITE has inspected 25 concrete culverts in Ohio in a same manner as it was mentioned in the "Metal Culverts" Section (Mitchell et al, 2005). Some of the characteristics of the 25 concrete culverts are listed in the Table 2.5.

Table 2.5: Properties of Concrete Culverts Studied in Ohio

Description	Reading	Characteristics
Shape	2 out of 25	horizontal ellipse
	4 out of 25	slab on top
	5 out of 25	circular
	14 out of 25	box
Age	1 out of 25	less than 25 year old
	7 out of 25	25 to 50 years old
	6 out of 25	50 to 75 years old
	5 out of 25	more than 75 years old
	6 out of 25	unknown
Span	9 out of 25	2 to 5 ft
	5 out of 25	5 to 8 ft. span
	1 out of 25	larger than 8 ft span
Soil Cover	22 out of 25	0 to 5 ft
	1 out of 25	5 to 10 ft
	1 out of 25	10 to 20 ft

Description	Reading	Characteristics
Road Type	2 out of 25	interstate
	2 out of 25	U.S. Highway
	21 out of 25	State Highway
Annual Daily Traffic	7 out of 25	less than 1000
	13 out of 25	1000 to 4000
	2 out of 25	4000 to 10000
	3 out of 25	more than 30000
pH	1 out of 25	less than 6
	22 out of 25	6 to 8
	2 out of 25	more than 8
Abrasiveness	18 out of 25	abrasive
	7 out of 25	not abrasive

According to the results of the inspections, the service life is determined as 70 to 80 years. The authors determined that age, pH and abrasiveness were significant parameters which were affecting the culvert rating. The regression equations generated in this study had an R-squared value of 0.53. Authors state that deteriorated headwalls, crown region/top slab deterioration and transverse shear cracks were the most common problems in the inspected concrete culverts however the

There were no serious alignment problems for concrete culverts and there was no problem with the roadway surface passing over the culverts. Authors also added that cast-in-place box culverts and reinforced concrete circular/elliptical pipe culverts had exhibited similar performances.

Hurd (1990) investigated the performance of precast reinforced box concrete culverts in Ohio from 1988 to 1990. 133 culverts were inspected in this study. According to the results, all of the culvert inverts had an excellent condition; however nine of the culverts had deteriorations on the top slab of the end sections. The probable reason of this deterioration was due to exposure to roadway deicing salts. It was suggested to place a surface sealer on the external top slab of culverts having less than 3 ft of cover height.

In order to extend the service life of concrete culverts some protection methods are used. Hurd evaluated one of these protection methods in his paper titled as “Field performance of protective linings for concrete and corrugated steel pipe culverts.” In this study it is stated that epoxy-coating is used in Ohio for corrosive culvert sites since 1973 and it was initially used for sites where vitrified-clay protection was not available. Authors inspected a total number of 26 culverts where only one of the culverts was rated as poor, and the rest being either excellent or very good. The reason for the poor rating was explained as the detrimental effect of long-term sunlight exposure and/or poor bonding between the coating and concrete during the manufacturing process. As a result it was concluded that epoxy coating gives satisfactory protection at acidic sites with nonabrasive to moderately abrasive flows.

Concrete culvert structure usually do not face structural problems due to their rigidity if they are designed according to the specifications however the soil conditions adjacent to the concrete pipes can create problems. For example, according to Heger and Selig, the soft soil adjacent to the pipe under high fills can cause increased earth loads on the structure and they suggested that soft soils should be removed from each side of the culvert for a distance of at least one diameter.

To sum up, according to the investigations presented, the performance of concrete culverts depend on the pH of the flow, age of the culvert, sediment depth, slope, the presence of roadway deicing salts and the soil strata next to the culvert. Corrosion and abrasion may still be a major problem in some of the extremely corrosive environments. This condition may lead to durability problems, slabbing, spalling and joint problems in precast concrete culverts.

Plastic Culverts

Technological improvements in material science enabled pipe manufacturers to produce lightweight and durable pipes from polymers. Plastic pipes provide equivalent service life in a potentially broader range of conditions than either metal or concrete. The two most commonly used plastic materials for culvert applications are Polyvinyl Chloride (PVC) and High Density Polyethylene (HDPE). Both materials are unaffected by the chemical and corrosive elements typically found in soils. Table 2.6 presents an inventory of plastic culverts studied by ORITE.

Table 2.6: Properties of Plastic Culverts Studied in Ohio

Description	Inventory	Characteristics
Material	6 out of 10	High Density Polyethylene (Circular)
	4 out of 10	PVC (Circular)
Age	9 out of 10	less than 10 year old
	1 out 10	20 to 30 years old
Diameter	5 out of 10	2 to 3 ft.
	4 out of 10	3 to 4 ft
	1 out of 10	larger than 4 ft
Soil Cover	4 out of 10	0 to 5 ft.
	1 out of 10	5 to 10 ft
	4 out of 10	10 to 20 ft
	1 out of 10	larger than 20 ft
Road Type	3 out of 10	U.S. Highway
	4 out of 10	State Highway
	3 out of 10	Others
pH	10 out of 10	6 to 8

Abrasiveness	9 out of 10	abrasive
	1 out of 10	not abrasive

Polyvinyl Chloride (PVC) and High Density Polyethylene (HDPE) have exhibited excellent abrasive resistance, particularly when acidic or alkaline conditions are present. ORITE has inspected 10 thermoplastic pipes in Ohio for the project "Risk Assessment and Update of Inspection Procedure for Culverts" (Mitchell et al, 2005).According to the results of the inspections authors indicate that the most frequently observed problems were the deflection of the pipes for more than 7.5% followed by the localized buckling and followed by the misalignment problems at joints.

Gassman et al (2002) conducted investigation on forty five HDPE culverts in South Carolina. It was found that majority of the high density polyethylene (HDPE) pipes were deflected less than 5%. Visual inspections and measurements were carried out with respect to AASHTO and ASTM specifications. According to those inspections, 36% of the pipes exhibited minor cracks, punctures, or bulges. The reason of these deflections and cracks were given as improper installation techniques such as poor bedding of soils and inadequate backfilling.

Sargand et al (2002) studied the long term behavior of profile-wall High Density Polyethylene Pipes under deep soil cover. Two pipes with 1050 mm diameter fewer than 20 ft and 40 ft over cover were monitored in this study. According to the results of the paper, both pipes were found to have a satisfactory performance and the sandy soil with a 96% relative compaction was determined as good as the crushed limestone with the same compaction level.

A similar study is performed by Adams et al (1989) 24 inch diameter corrugated Polyethylene pipe was placed under 95 ft of fill. According to the results of this study the pipe was observed to remain in its circular shape and the vertical diameter decrease was observed around 4 percent whereas the horizontal diameter increase was observed around 0.4 percent. The earth pressure was also measured at the crown section of the pipe and it was determined to be only 20 percent of the vertical embankment pressure. This study shows the significance of soil-pipe interaction.

Plastic pipes can be manufactured with a desired durability to withstand the effects of corrosion and abrasion. However, installation and backfilling procedures have to be handled with care. As the other flexible culvert types, plastic culvert also depend on the soil – structure interaction in terms of structural stability. Improper design and/or installation techniques may lead to deflections and misalignments in plastic culverts.

Aluminum Culverts

Aluminum has been used as a construction material for drainage structures for approximately 50 years in the United States. Having a better corrosion resistance compared to metal culverts made aluminum culverts the choice of designers in many sites. Allemeier gives the advantages and disadvantages of aluminum as follows, Advantages of Aluminum are,

- They are ideal for shipping due to their very light weight
- Their sizes and shapes vary in a large range
- The thickness of the sheets and also the corrugations can be selected from a wide range in order to obtain the required strength
- Easy and fast assembling and installation procedures
- They have better resistance against corrosion than steel pipes in salty water.

Disadvantages of Aluminum are,

- Corrugation roughness decreases the rate of flow except for the smooth-lines pipes
- In case of significant amount of presence of sand and/or rock in a high velocity stream, abrasion may cause loss of material
- They are generally more expensive than steel pipes.
- Installation procedures have to be handled more carefully compared to steel pipes due to higher flexibility.
- They are more sensitive to the live and dead loads compared to the steel pipes due to higher flexibility.

Summerson (1984) explains the high corrosion resistance of aluminum pipes with the oxide films produced by the chemical reactions on the surface of the pipe. The author states that this very thin layer of oxide film is extremely stable and therefore does not show any reaction over a wide range of conditions and even in a case of mechanical damage such as abrasion the film refreshes itself instantly. The author further states that corrosion may be a problem on some defective areas on the pipe where the oxide film has some micro defects due to the metallurgical properties however; this corrosion takes place locally as a form of pitting therefore it does not affect the overall durability of the pipe drastically. Summerson does field inspections and laboratory tests in California in order to prove the theoretical corrosion resistance of aluminum culverts. According to the results of the inspection, when aluminum pipes are used on the sites where pH values are within the specifications (between 4 and 9) and the minimum resistivity is 500 ohm-cm aluminum pipes show excellent performance.

Bellair and Ewing (1984) investigated and compared the metal-loss rates observed in uncoated steel and aluminum culverts in New York. The field survey included 190 galvanized steel culverts and 35 aluminum culverts. According to their findings, aluminum culverts showed significantly better performance than uncoated steel culverts throughout the state and with the application of statistical analysis to the field data they have reached the conclusion that 35 mil thickness of material was enough for a 70-year design life which was already within the minimum thickness requirement.

Hurd et al, (1991) investigated the structural performance of an aluminum box culvert during the installation and live load application on the structure. The culvert selected for investigation was a corrugated aluminum box culvert with a span of 14 ft 10 in., a rise of 4 ft 10 in. and a length of 42 ft. Deflections and strains along the culvert were recorded and results were analyzed with computer programs and a finite element analysis was made. As a result of the analysis it was concluded that the structural performance of the aluminum culvert was satisfactory and finite element analysis was proved to be beneficial in analyzing and designing this kind of structures. Some criticism about the computer program CANDE was made after comparing the actual measurements and computer outputs.

To sum up, aluminum culverts and aluminum coated culverts appear to have better corrosion resistance compared to steel culverts if they are used on the sites within the design limits. Structurally, more care should be given in the installation and backfilling process due to the higher flexibility.

2.12.2 Culvert Classification by Shapes

The common shapes of culverts used are,

- Circular.
- Pipe Arch or Elliptical.
- Arches.
- Box Sections.
- Multiple Barrels.

Circular

The circular shape is the most common shape among culvert materials. It is hydraulically and structurally efficient under most conditions. Possible hydraulic problems are that it generally causes some reduction in stream width during low flows and it may clog due to diminishing free surfaces as the pipe fills beyond the midpoint.

Elliptical or Pipe Arch

Elliptical culverts are used instead of circular pipe when distance from channel invert to pavement surface is limited or when a wider section is desirable for low flow levels. These pipes are also prone to clogging as the depth of flow increases and the free surface diminishes. Elliptical shaped culverts are not structurally as efficient as a circular shape. They are used in areas with limited vertical clearance and low cover conditions.

Arches

Arch culverts have no culvert barrel material at the bottom and offer less of an obstruction to the waterway than the pipe arches and can be used to provide a natural stream bottom, where the stream bottom is naturally erosion and abrasion resistant. Foundation conditions must be adequate to support the footings.

Box Sections or Rectangular

Rectangular culverts are easily adaptable to a wide range of site conditions, including sites that require low profile structures. Due to angular corners, boxes are not structurally and hydraulically efficient as other culvert shapes.

Multiple Barrels

Multiple barrels (Figure 2.9) are used to obtain adequate hydraulic capacity under low embankments or for a wide waterway. Sometimes, they are prone to clogging as the area between the barrels tends to catch debris and sediment.

Figure 2.9: Multiple Barrel Culverts
(Source: American Concrete Industries, 2008)

2.13 Culvert Appurtenances and End Treatments (FHWA, 1986)

Culvert appurtenances are structural and functional portions of the culvert that improve its flow characteristics and functionality. The primary appurtenances include:

- Headwalls or Endwalls
- Wingwalls
- Energy Dissipaters
- Aprons
- Fish Passage Device
- Projecting
- Skewed
- Mitered

2.13.1 Headwalls

Headwalls (Figure 2.10) are entrance structures that protect the embankment from erosion and improve the hydraulic efficiency of the culvert. They provide embankment stability and protection from buoyancy. Properly designed, they shorten the required structure length and reduce maintenance damage. They also provide structural protection to inlets and outlets.

2.13.2 Wingwalls

Wingwalls (Figure 2.10) recess the inflow or outflow end of the culvert barrel. They anchor the pipe to prevent disjointing caused by excessive pressures and control erosion and scour resulting from excessive velocities and turbulences. They are generally used:

- To retain the roadway embankment.
- Where the side slopes of the channel are unstable.
- Where the culvert is skewed to the normal channel flow.

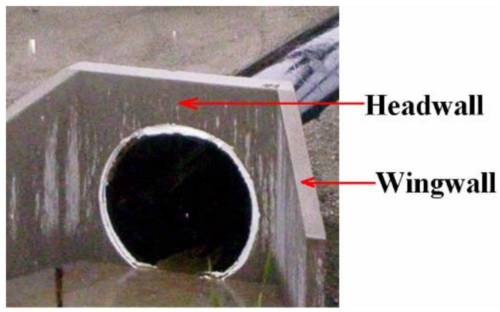


Figure 2.10: Culvert Showing Headwall and Wingwall

Other benefits of end structures are that the tapered sides merge with the slope to provide a neat appearance with erosion, sedimentation, scour, blockage, and vegetation growth reduction.

2.13.3 Energy Dissipaters

Energy dissipaters are any structures designed to protect downstream areas from erosion by reducing the velocity of flow to acceptable limits. They are used to reduce the energy of flowing water and protect the highway, streambed, and adjacent property. Energy dissipaters include several types – riprap basins, impact basins, drop structures and hydraulic jumps.

A *riprap basin* is riprapped floor constructed at the approximate depth of the scour. It is classified as either graded or ungraded. Graded riprap forms a flexible self-healing cover, while ungraded riprap is more rigid and cannot withstand movement of the stones. *Impact basins* dissipate energy through the impact of flowing water with various devices in the basin. One such device is a hook-type dissipater designed for culverts with low tailwater. A riprap basin is shown in Figure 2.11

Drop structures change the channel slope from steep to mild by placing a series of gentle slopes and vertical drops. They control the slope in such a way that highly erosive velocities never develop. The kinetic energy gained by water as it drops over the crest is dissipated by aprons or stilling basins. The *hydraulic jump* is a natural phenomenon that occurs when supercritical flow changes to subcritical flow. This abrupt change in flow condition is accompanied by turbulence and loss of energy. It is an effective energy dissipation device that is often employed to control erosion at hydraulic structure.

Figure 2.11: Riprap Basin to Protect Streambed and Stream Slope

2.13.4 Aprons

Aprons are used at the inlets of the culvert to prevent scouring and undermining from high headwater depths or from approach velocity in the channel to eliminate clogging by vegetation growth. They are used to improve hydraulic efficiency at the inlets. Most aprons include a cutoff wall to protect from undermining.

2.13.5 Fish Passage

Culverts exhibit potential obstacles to fish passage along the waterway. The two most common problems are excessive water velocities through the culvert or high vertical barriers for fish to overcome. Other problems include the depth of water in the culvert at high, moderate, or low flows, which is not feasible with the swimming capabilities of the fish, the coincidence of design flows with seasonal time of fish migration, icing and debris problem.

To successfully provide fish passage through the culvert, modifications to the barrel to decrease the velocity and increase the depth of flow by increasing roughness elements can be made. In addition, fish ladders and backwater structures such as weirs, gabions, etc., or a fish pool can be provided at the culvert outlet.

2.13.6 Projecting

This is a type of end treatment that has no end structure attached to ends of the culvert barrel. The barrel is made to extend beyond the face of the embankment.

2.13.7 Mitered End

A mitered end treatment is a culvert end that has been cut to match the embankment slope. Mitered ends are commonly provided for corrugated metal pipe and are called as beveled end.

2.13.8 Skewed End

Culverts that are not perpendicular to the centerline of the roadway are called skewed. If the ends are cut to be parallel to the roadway, it is called a skewed end treatment.

2.14 Factors Influencing Performance of a Culvert

Performance of a culvert is directly proportional to its remaining design service life (AASHTO, 1999). It is defined as the period of service without a need for major repairs. For corrugated metal pipes (CMP), this will normally be the period in years from installation until deterioration reaches the point of either perforation of any point on the culvert or some specified percent of metal loss. Reinforced concrete pipe service life is the period from its installation until reinforcing steel is exposed, or a crack signifying severe distress develops. Plastic pipe service life may be considered at an end when excessive cracking, perforation, or deflection has occurred. Culvert service life can also be affected by debris damage or erosion caused by major storm events, improper manufacturing, or handling of the culvert. Major factors influencing the performance or service life of a culvert are:

- Durability factors
  - Corrosion
  - Abrasion
  - Erosion
- Loss of Structural Integrity
  - Joint Separation
  - Misalignment
  - Seam Defects
- Environmental Factors
  - Scaling
  - Delamination
  - Spalling
  - Efflorescence
  - Honeycombs
  - Popouts

2.14.1 Durability

Durability is the property to resist erosion, material degradation, and subsequent loss of function due to environmental and/or other service conditions. Abrasion and corrosion are the most common durability problems for culverts. Proper attention must be given to these problems in the design phase. Field inspection of culverts existing on the same stream will prove valuable in assessing potential problems.

The Ohio Research Institute for Transportation and Environment (ORITE) conducted research on sixty culverts in May 2005 to determine the significant parameters for culvert durability. The study determined that culvert alignment was not a problem in most of the metal culvert sites and stress cracks were not observed at the bolt lines of any of the metal culverts. Perforations at the inlet and flow line, scour at inlet, outlet, and headwall were the most frequently encountered problems. According to the authors, pH, abrasiveness, flow velocity, age and rise were the significant parameters and invert region was more sensitive to material degradation compared to other regions. Two major factor influencing durability are as follows:

Corrosion – Corrosion is the destruction of pipe materials by chemical action. Metal culverts or reinforcements in concrete pipes are attacked by corrosion as the process of returning metals to their native state of oxides or salts. Figure 2.12 shows corrosion in metal culvert. *Chemical corrosion* of culverts may occur in the presence of soils and water containing acids, alkalis, dissolved salts, and organic industrial wastes. Sulfates, carbonates, and chlorides degrade concrete which is a process often accelerated in regions where freeze-thaw cycles leave the material open to deeper penetration by the offending elements. *Electrochemical corrosion* of metal culverts may occur due to the presence of water or some other liquid to act as an electrolyte, as well as materials acting as an anode, cathode, and conductor. As electrons move from anode to cathode, metal ions are released into solution, with characteristic pitting at the anode. The culvert will act as both anode and cathode forming an electrolytic cell around the material. Figure 2.12 shows a similar type of corrosion in culvert.

Figure 2.12: Corrosion in Culverts

Hydrogen Ion Concentration (pH) – pH is defined as the log of the reciprocal of the concentration of hydrogen ion in a solution. Values of pH in natural waters are within a range of 4 – 10. A pH less than 5.5 is usually considered to be strongly acidic, while values of 8.5 or greater are strongly alkaline. The presence of oxygen at the metal surface is necessary for the corrosion to occur and is independent of the pH. However, pH reading that is either highly acidic or alkaline is indicative of a heightened potential for corrosion. A pH value between 5.5 and 8.5 are not considered detrimental to culvert life.

Soil Resistivity – Resistivity of the soil is a measure of soils ability to conduct electrical current. It is affected by the nature, concentration of dissolved salts, temperature, moisture content, compactness, and the presence of inert materials such as stones and gravel. The greater the resistivity of the soil, the less capable the soil is of conducting electricity and the lower the corrosive potential.

Chlorides – Dissolved salts containing chloride ions can enhance culvert durability if their presence decreases oxygen solubility. Nevertheless, the corrosive potential is increased as the negative chloride ion decreases the resistivity of the soil and water destroying the protective film on the anodic area. Chlorides attack unprotected metal culverts and reinforcing steel in concrete culverts if concrete cover is inadequate, cracked or highly permeable.

Abrasion – Abrasion is the gradual wearing away of the culvert wall due to the impingement of bed load and suspended material. Abrasive potential is a function of culvert material, frequency, velocity of flow in the culvert, and composition of bed load. The effect of abrasion can be seen in the pipe invert where exposure is most severe. It can result in loss of pipe strength or reduction in hydraulic quality as they gradually remove wall material, as abrasion is a precursor to accelerated corrosion.

Debris – Debris is carried by storm water and can be a destructive element as their potential is related to clogging of the culvert with the effect of overtopping and erosion. (Figure 2.13) Large volume of debris can increase bed load abrasion. The most common types of debris found in culverts are boulders, trees, shrubs, ice, etc.

Figure 2.13: Debris at the Opening of the Culvert

Bed load – Bed load is the main cause for abrasion. Figure 2.14 shows abrasion in culvert. Critical factors in evaluating bed load potential are the size, shape, and hardness of the bed load material, and the velocity and frequency of flow in the culvert. Flow velocities greater than 4.5 m/sec that carry a bed load are considered very abrasive. Steel culverts are most susceptible to the dual action of abrasion and corrosion when they are exposed to low resistivity and/or low pH environments, which shorten their service life.

Figure 2.14: Deterioration due to Abrasion (Caltrans, 2003)

Erosion – Erosion may take place if a defined approach channel is not aligned with the culvert axis. If the culvert is not aligned with the channel and the channel is modified to bend into the culvert, erosion can occur at the bend in the channel. Erosion of the embankment at inlet may be reduced by constructing the culvert into the fill slope and retaining the fill by headwall and wingwalls. Good compaction of backfill material is essential to reduce the possibility of erosion. Where soils are quite erosive, special impervious bedding and backfill materials should be placed for a short distance at the culvert entrance. The problem at culvert outlet is scouring. Local scour is the result of high-velocity flow at the culvert outlet, but its effect extends only a limited distance downstream as the velocity transitions to outlet channel conditions. Long, smooth-barrel culverts on steep slopes will produce the highest velocities causing highest erosion at outlet. A common mitigation measure for small culverts is to provide riprap aprons. If the flow velocity is very high and which is not controllable by riprap aprons then energy dissipaters should be provided.

2.14.2 Loss of Structural Integrity

Loss of structural integrity shortens the service life of culverts or affects its performance. They are due to defects in manufacture of culvert pipes, improper construction techniques, or from the effects of a large storm event. Losses of structural integrity occurs over a period of time and are related to factors such as piping seepage, soil movement, scour, and backfill soil loss. Common defects found in any culvert type are:

Joint Separation – Joint separation depends upon the type of joint used. Joints with an external sleeve allow a limited amount of axial separation between abutted pipe ends since the external sleeve will typically maintain joint integrity and limit infiltration. For bell and spigot type joints, there is no allowable separation. Some minimum amount of overlap is usually specified.

Causes of joint separation or insufficient overlap are due to inadequate quality control during construction like uneven bedding, poorly compacted backfilling operations, or unexpected settlements. Joint problems also occur when culverts are installed under existing roadways by constructing half the width at a time. Adequate backfill compaction and alignment at the point where the two halves meet is very difficult and proper joining may not occur. Natural hazards like earthquakes and landslides also lead to joint separation in culverts. Anchorage and other higher strength joint connection are specified under these conditions.

Figure 2.15: Culvert Pipe showing Cracks and Joint Separation

Misalignment – Problems that causes joint separation can also leads to misalignment. Misalignments are deviations from planned alignments. Segmental construction, where portions of a single pipe are constructed at separate times, leads to misalignment due to differential settlement rates, and the difficulty in maintaining constant grade through the area of segment connection. Poor vertical alignment may indicate problems with the subgrade beneath the pipe bedding. They trap debris and sediment and may impede flow. This could saturate the soil beneath and around the culvert, reducing the soils stability. Minor vertical and horizontal misalignment is not a problem unless it causes shape or joint problems.

Seam Defects – Seam defects are the result of poor manufacturing or improper handling of culvert materials. Types of defects include loose fasteners, cocked or cusped seams, seam cracking, bolt tipping, dents, and localized damage.

The longitudinal seams in steel structures are bolted with high strength bolts in crests and valleys of the corrugations. These are bearing type connections and are not dependent on the minimum clamping force of bolt tension to develop interface friction between the plates. Fasteners must be checked for their tightness, as any *loose or missing fasteners* may lead to collapse of the structure. The lapped and bolted longitudinal seams affect the shape and curvature of the structure. Improper erection or fabrication can result in *cocked or cusped seams*. Cusped seams alter the structure's shape, appearance, and dimensions from that designed. A cocked seam can result in loss of backfill and may reduce the ultimate ring compression strength of the seam.

Seam cracking – It develops along the boltholes of longitudinal seams. As cracking progresses, the structure may lose ring compression capability of the seam and this could result in deformation of the culvert or possible failure. Longitudinal cracks are most serious when accompanied by significant deflection, distortion, and other conditions indicative of backfill or soil problems. Cracking may be caused by improper erection practice such as using bolting force to lay down a badly cocked seam.

Bolted seams develop their ultimate strength under compression. *Bolt tipping* occurs when the plate slip. As the plates begin to slip, the bolt shank plastically elongates the bolts tip, and the boltholes. Excessive compression on a seam could result in plate deformations around the tipped bolts and failure is reached when the bolts are pulled through the plates.

Pipe wall damages such as *dents*, *bulges*, *creases*, and *cracks* are found when the defects are extensive. They impair the integrity of the barrel in ring compression or permit infiltration of backfill. When the deformation type damages are critical, they result in distorted cross-sectional shapes.

Longitudinal Cracks - Concrete is strong in compression and weak in tension. Reinforcing steel is provided to handle the tensile stresses. Hairline longitudinal cracks in the crown or invert indicate that steel has received part of the load. Longitudinal cracking in excess of 0.1 inch in width may indicate overloading or poor bedding. If the pipe is placed on hard material and backfill is not adequately compacted around the pipe or under the haunches of the pipe, loads will be concentrated along the bottom of the pipe and may result in flexure or shear cracking as shown in the Figure 2.16.

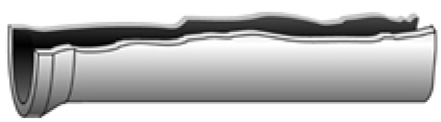


Figure 2.16: Longitudinal Crack in a Culvert Pipe
(Source: National Research Council Canada, 2006)

Transverse Cracks **-** Poor bedding, as shown in Figure 2.17, causes transverse cracks or circumferential cracks. Cracks occur across the bottom or crown of the pipe when it is supported at the ends of each section. This is the result of poor installation practices, such as not providing sufficient depth of suitable bedding material.

Figure 2.17: Transverse Cracks in a Culvert Pipe

2.14.3 Environmental Factors (Caltrans, 2003)

Scaling – Scaling is the gradual and continuing loss of aggregate over an area due to the chemical breakdown of the cement bond. It starts as a localized small patch, which merges and extends to expose large areas. Light scaling does not expose the coarse aggregate, moderate scaling exposes and may involve loss up to 1/8 to 3/8 inch of the surface mortar. In severe scaling, more surfaces will be lost (NRMCA, 1998).

Figure 2.18: Scaling exposed on Concrete Surface.
(Source: Photomac Construction industries, 2008)

Delamination – Delamination is the sub surface separation of concrete into layers. It is caused by corrosion of internal expansion. The extent of deterioration in delamination is often unknown until the delamination is opened up.

Figure 2.19: Delamination on a Concrete Surface.
(Source: Concrete Restoration and Construction, 2007)

Spalling – Spalling is a depression in concrete caused by a separation of a portion of the surface concrete where the topping is popping or peeling off. This is due to the action of weak top surface, overworking of the concrete, low entrainment, excessive water, and freeze thaw cycling.

Figure 2.20: Spalling on a Concrete Surface.
(Source: Caltrans, 2003)

Efflorescence – Efflorescence is a combination of calcium carbonate leached out of the cement paste and other recrystallized carbonate and chloride compounds. It is a white crystalline or powdery deposit on the surface of the concrete surface and is caused by water seeping through the culvert wall. The water dissolves salts inside the concrete surface, while moving through it, and then evaporates leaving the salts on the surface. Figure 2.21 shows efflorescence of the concrete surface.

Figure 2.21: Formation of Efflorescence on a Concrete Surface.
(Source: House Check, 2007)

Honeycombs – Honeycombs (Figure 2.22) are coarse aggregates on the surface without any mortar covering or surrounding the aggregate particles. The honeycombing may extend deep inside the concrete and are caused by a poorly graded concrete mix or by insufficient vibration at the time of placement. Honeycombing must be taken care of when noticed and repaired to prevent further deterioration of the concrete surface.

Figure 2.22: Honeycombing on a concrete surface.
(Source**:** Department of Architectural Engineering, 2006)

Popouts – Popouts are conical fragments that break out of the surface of the concrete leaving small holes as shown in Figure 2.23. Popouts occur because the concrete has been overworked, allowing the aggregates to drift upward toward the surface.

Figure 2.23: Pop-outs in a Concrete Structure.
(Source**:** Concrete Sealers, Specialty Coatings and Consulting, 2006)

Other factors, which influence the performance or service life of a culvert, are:

- Size, shape, hardness, and volume of bed load.
- Volume, velocity, and frequency of stream flow in the culvert.
- Material characteristics of the culvert.
- Anticipated changes in the watershed upstream of the culvert, such as industrial or residential development (AASHTO, 1999).

2.15 Chapter Summary

This chapter reviewed various concepts and principles of culvert asset management. The GASB 34, which was introduced in 1999, recommends that all state and local agencies to preserve the infrastructure assets using modified approach. The modified approach follows the asset management principles, which are comprehensive and structured approaches to the long-term management of infrastructure assets. The key feature of an asset management strategy is its customer focus and being mission driven. It results in cost savings over the emergency repair of culvert failures, which is an increasing problem in the nation. Understanding the engineering aspects of the culvert is essential in developing an inventory and inspection model. This chapter briefly explained hydraulic and structural concepts, such as inlet control, outlet control, types of flow, flexible and rigid culvert behavior, and culvert types based on shape and material. In addition, this chapter identified various culvert components, such as culvert appurtenances, end treatments, and provided various factors contributing to culvert deterioration such as material durability issues, loss of structural integration, and environmental factors.

CHAPTER 3.0

SURVEY OF CULVERT ASSET MANAGEMENT PRACTICES

3.1 Introduction to Survey

To evaluate the status of culvert asset management practices in the U.S. and Canada, a survey of transportation agencies (DOT's) was conducted by the research team. The objective of this survey was to understand the current development and implementation of culvert asset management in United States and Canada. The survey questionnaire was simple and focused on two main tasks: culvert inventory (12 questions) and inspection & decision support system (11 questions). The supporting documents to answer the questions were requested to be returned with the questionnaire for logical assessment of questions. Fifty (50) USDOTs and ten (10) Canadian DOTs were contacted and the best person to answer the survey was identified based on his or her position, experience, and work area. An invitation, with an electronic format of the survey was sent to all the participants. The responses were stored and monitored on the server. This chapter presents the statistical analyses of survey results, which clearly shows the need for a comprehensive culvert asset management strategy. Table 3.1 presents the list of US states and Canadian provinces who participated in the survey. Figure 3.1 illustrates a flow chart describing the steps taken to develop a culvert inventory and inspection manual.

Table 3.1: States Participated in the Culvert Asset Management Survey.

Alaska	Iowa	Missouri	Ohio	New Hampshire
Arkansas	Idaho	Maryland	Oregon	Nova Scotia
California	Illinois	Minnesota	Pennsylvania	Ontario
Delaware	Kansas	Nevada	Tennessee	Alberta
Florida	Louisiana	North Carolina	Virginia	Quebec
Georgia	Michigan	North Dakota	Washington State	Washington DC

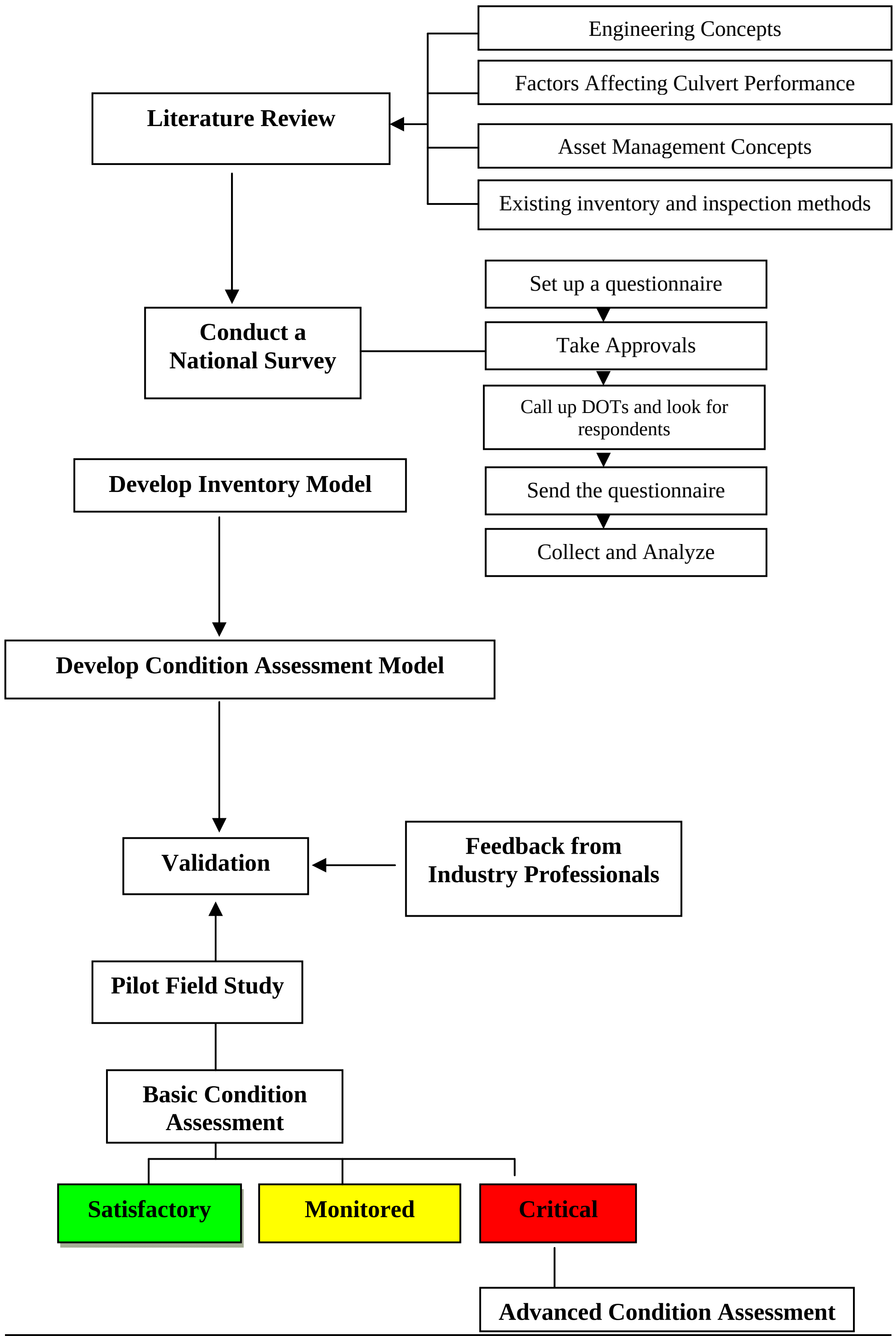


Figure 3.1: Flow Chart for Culvert Inventory and Inspection Model.

3.2 Culvert Inventory

More importance was given to understand the culvert inventory practices and guidelines followed in US and Canada. This is because a good inventory of culverts was the core foundation in developing an effective long-term asset management framework. The more we understand our culverts, the better strategies we can develop in preserving them. The survey questions were developed focusing on culvert inventory based on condition, size, material, design, inspection frequency and agency responsible for maintaining it. Overall response rate for this part of the survey was 70%. The seven questions on culvert inventory, responses and analysis are as follows:

1. What is the condition of majority of culverts in your state?

Total of 32 respondents responded for this question. Eighty one percent (81%) of the respondents felt that the culverts in their state were in good condition and have not given any indications of reaching their useful service life. Six percent (6%) of the respondents felt that their culvert were in very good condition and could serve their purpose without any danger/problems for few more years. Thirteen percent (13%) of the respondents felt that their culverts were in the verge of their useful service life and need some type of assessment protocols to track and assess their condition. Figure 3.2 and 3.3 shows the condition of majority of culverts in the U.S. and Canada.

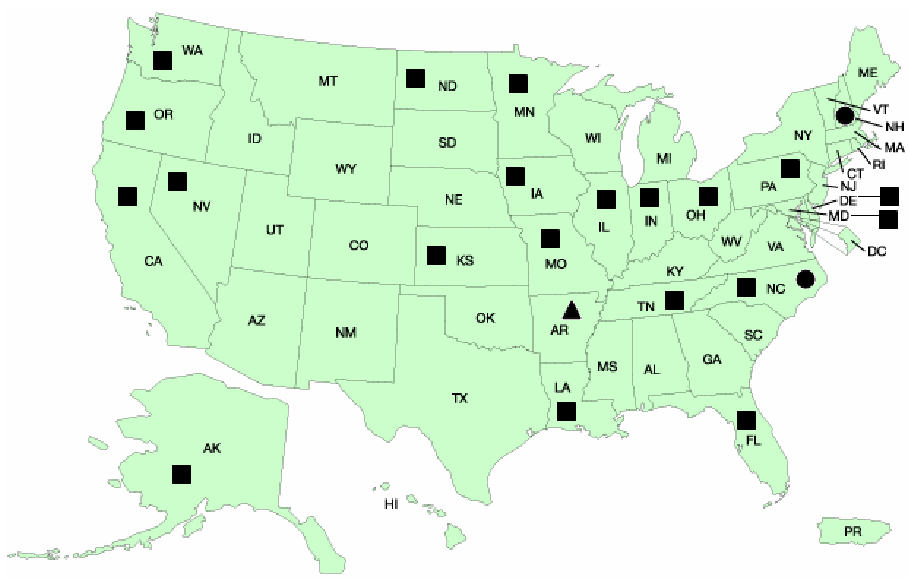


Figure 3.2: Condition of Majority of Culverts in United States.

● Very Good ■ Good ▲ Poor □ Deteriorated

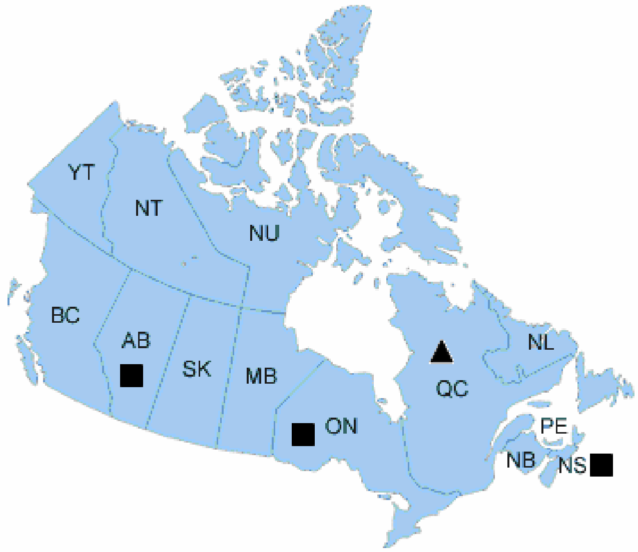


Figure 3.3: Condition of Majority of Culverts in Canada.

2. Does your state have a standard set of inventory guidelines for culverts?

This question was intended to study the type of guidelines the DOTs are following in tracking their culverts. These guidelines would provide the basis to develop our inventory framework. The response rate for this question was 85%. Sixty two percent (62%) of the respondents answered that they had some form of tracking system for the large culverts. They were not having any tracking system for smaller culverts spanning < 3'. Twenty four percent (24%) of the respondents answered that they had no tracking system for both large and small culverts. The state of Iowa uses information cards to track each culvert. Virginia has inventory module in their Asset Management System (AMS). They are working on the feasibility of using this system for culverts. North Carolina has no tracking system for culverts. They randomly select smaller culverts for inspection. Idaho does not differentiate between large and small culverts. They have a tracking system for large culverts spanning greater than 20' (bridges). They do not track small culverts, manholes, sewer holes. Pennsylvania tracks culverts spanning greater than 8' using their Bridge Management System (BMS). The state of Nevada follows the guidelines of Maintenance Management System (MMS). Ohio follows their Culvert Management System for guidelines in tracking their culverts. The state of Washington is developing a culvert inventory database that includes guidelines for culvert types, conditions and priority lists for replacement. Figures 3.4 and 3.5 show the states that have developed some form of guidelines to track their culverts. In Canada, Quebec, Alberta and Montreal have developed some form of guidelines for culvert inventory.

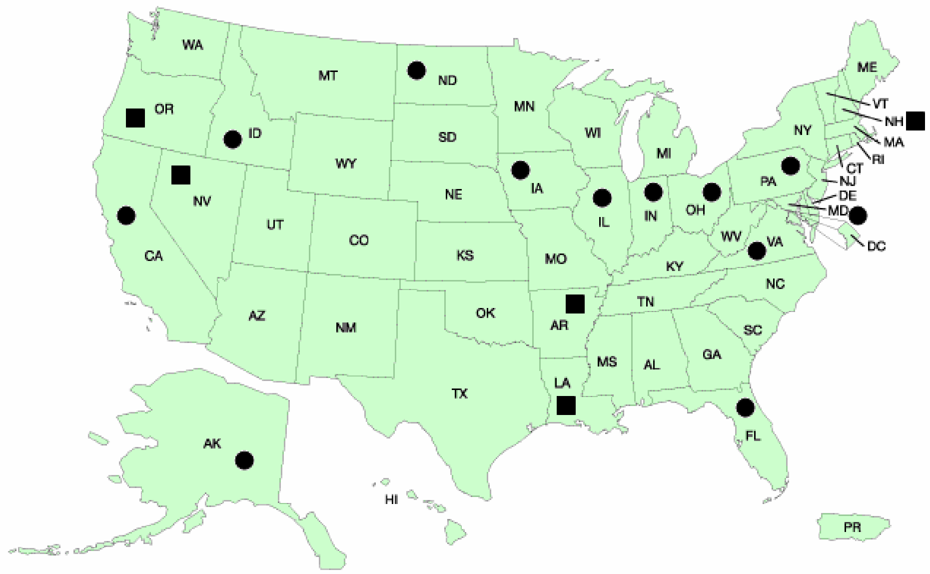


Figure 3.4: States that have Developed Standard Set of Guidelines for Culvert Inventory in United States

● Yes, there is a form of tracking system ▲ Development Phase

■ No, there is no form of tracking system for culverts

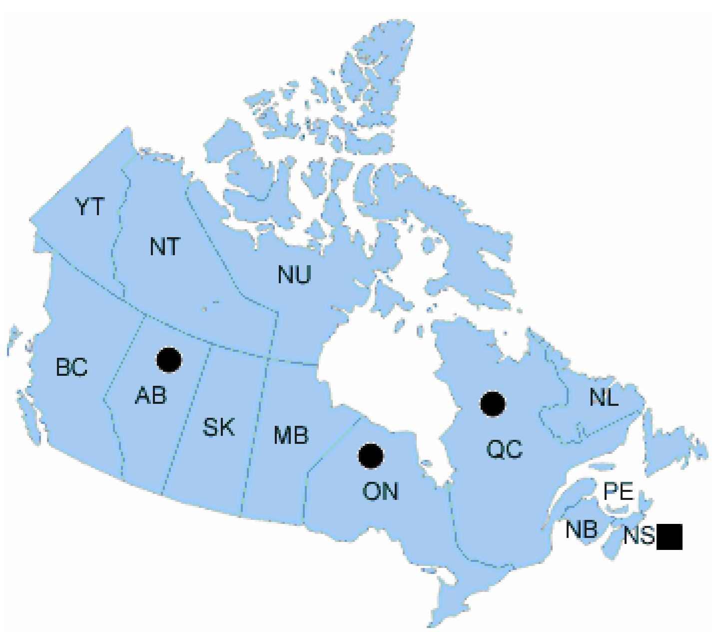


Figure 3.5: States that have Developed Standard Set of Guidelines for Culvert Inventory in Canada.

3. What are the minimum and maximum sizes of culverts in your state?

This question was to study the culvert size ranges followed in different states. The culvert definition is based upon its size. As, the size varies, the definition and its purpose varies. To design the global inventory/inspection framework, it is very important to understand these size ranges and accommodate them in the respective modules in the framework. Table 3.2 shows the different size ranges for concrete, metal and plastic culverts.

Table 3.2: Max and Min Culvert Sizes in United States and Canada

State	Concrete		Metal		Plastic	
	Min (in.)	Max (in.)	Min (in.)	Max (in.)	Min (in.)	Max (in.)
United States						
Arkansas	18	96	18	96	18	48
Alaska	120	-	120	-	120	-
California	18	240	18	240	18	240
Delaware	48	-	48	-	48	-
Idaho	-	240	-	240	-	-
Illinois	72	-	72	-	72	-
Indiana	48	240	48	240	48	240
Iowa	18	20	18	20	18	20
Maryland	36	239	36	239	36	239
Minnesota	12	120	12	120	12	-
New Hampshire	120	240 +	120	240 +	120	-
North Carolina	15	72	15	72	15	24
North Dakota	30	-	24	-	-	-
Ohio	12	120	12	120	12	60
Pennsylvania	96	240	96	240	24	96
Virginia*	5184 $in.^2$	-	5184 $in.^2$	-	5184 $in.^2$	-
Washington	18	240	18	240	18	60
Canada						
Alberta	60	-	60	-	60	-
Ontario	24	-	24	-	24	-

*The data obtained from Virginia was in terms of cross sectional area, or "$in.^2$" Due to incomplete information on the shape of the culvert, we did not converted to "in."

4. Is the original design of majority of culverts based on a 10-, 20-, 50-, or 100-year flood or other than these?

This question focused on the inventory of design data. It is very important to record the original design peak flow of every culvert. This data can be related to the condition of the culvert at any point of time and can be prioritized for maintenance. The response rate for this question was 62%. Most of the respondents (21%) responded that majority of their culverts were designed for 50 year flood. Figure 3.6 shows the graph of number of responses to the culvert's design.

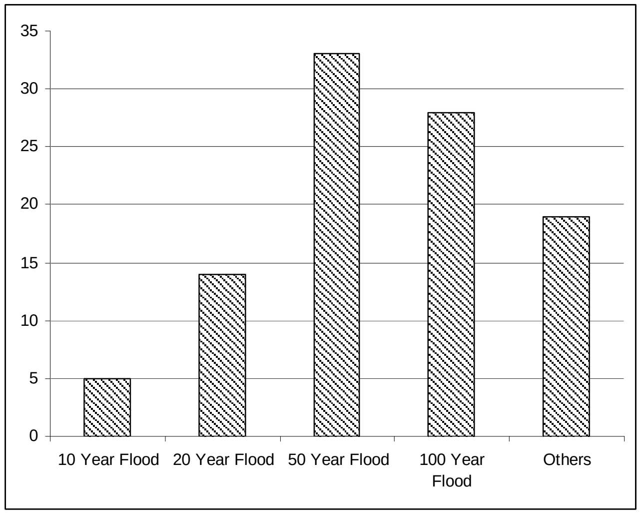


Figure 3.6: Graph of Number of Responses to Culvert Design

5. Does your DOT have a culvert dictionary?

Culvert dictionary is a list or database of all components of a culvert. It would serve as a checklist during the inventory or inspection process. The response data from this question would indicate the number of states that have developed some kind of checklist for culverts. The total response for this question is 24 out of 34 (70% response rate). Eleven (11) DOTs indicated that they have some kind of culvert dictionary or checklist for culvert inventory and inspection. Four (4) DOTs are in the process of developing a culvert dictionary. Figure 3.7 illustrates the survey results.

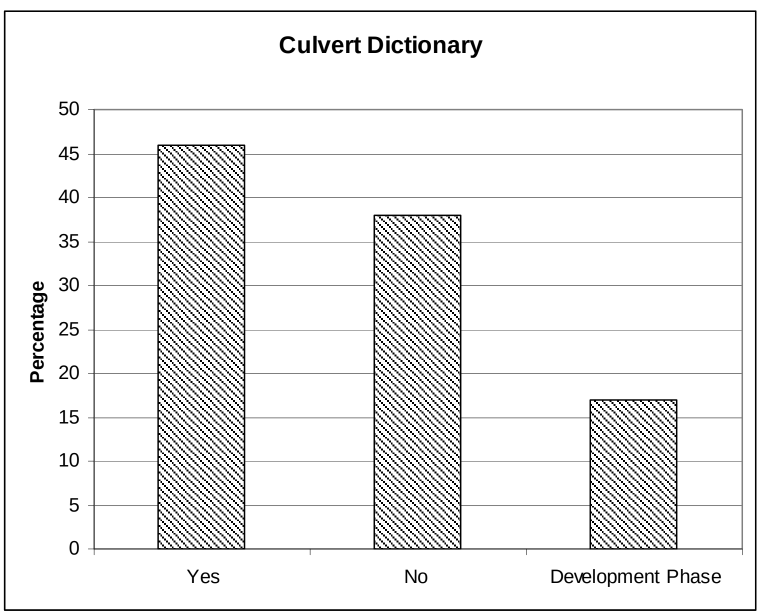


Figure 3.7: DOTs Response to Culvert Dictionary.

6. Do you have any failure cases reported?

The objective of this question was to understand if DOTs record and manage the failure information of the culverts. This information can be used to understand the failure modes of different types of culverts. The failure modes are very useful in condition assessment and failure prediction of culverts. The DOTs response to this question was that 75% of the agencies record the failure information, 20% of the agencies do not record the failure information and 5% of the agencies are working towards setting up a tracking system for failed culverts.

7. How often do you inspect culverts located on state highways and interstates?

The inspection frequency is an important parameter for both culvert inventory and inspection. Usually the culverts must be inspected for every 2 years due to change in population, change in loads due to traffic movement, change in climatic and geographical locations, changes in user needs and finally changes in design peak flows. Figure 3.8 shows the inspection frequencies and DOT responses.

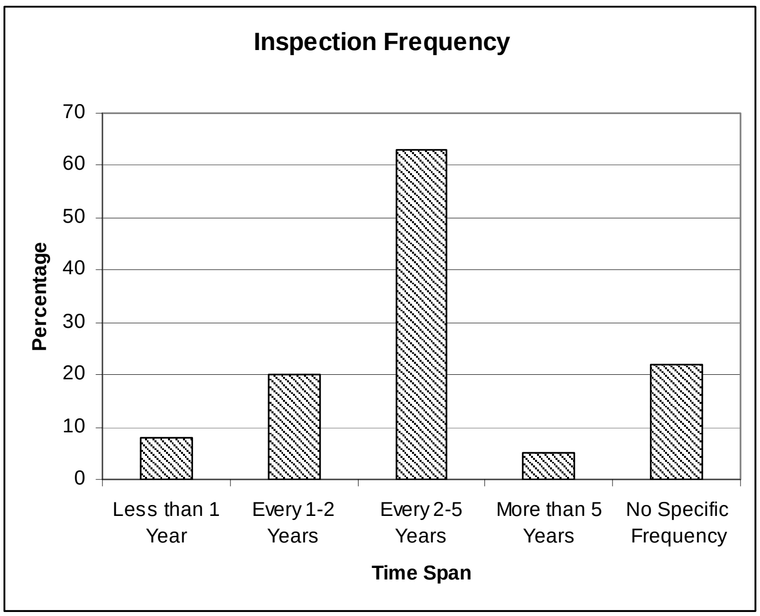


Figure 3.8: Culvert Inspection Frequencies.

3.3 Culvert Inspection and Decision Support System (DSS)

The second category of the survey focused on the culvert inspection and DSS. As the culverts reach the end of their design life, and due to changing environmental, structural and hydrological behavior of the culvert, it is very necessary to have an inspection program as a part of culvert asset management system. The following survey questions deal with the culvert components and inspection procedures.

8. Does your agency have a standard set of inspection guidelines for culverts?

Twenty six (26) DOTs responded to this question at a response rate of 76%. The state of Illinois follows the inspection guidelines posted on their website under the structural category. Virginia inspects culverts greater than or equal to 36 square feet in gross openings as per National Bridge Inspection Standards (NBIS) and Federal Highway Association (FHA). For culverts having longer inspection frequencies (greater than 48 months) follow National Bridge Inventory (NBI) guidelines. The state of North Carolina has the inspection guidelines covered in their Maintenance Condition Assessment Manual. California groups the culverts under different inspection categories and inspects them using their state wide standard culvert guidelines. Ohio follows their Culvert Management Manual (CMM). The state of Washington is working on developing standardized guidelines for their culverts. In Canada, Ontario follows the Ontario Structural Inspection Manual (OSIM). Figure 3.9 and 3.10 shows the graphical representation of the US states and Canadian provinces having culvert inspection guidelines.

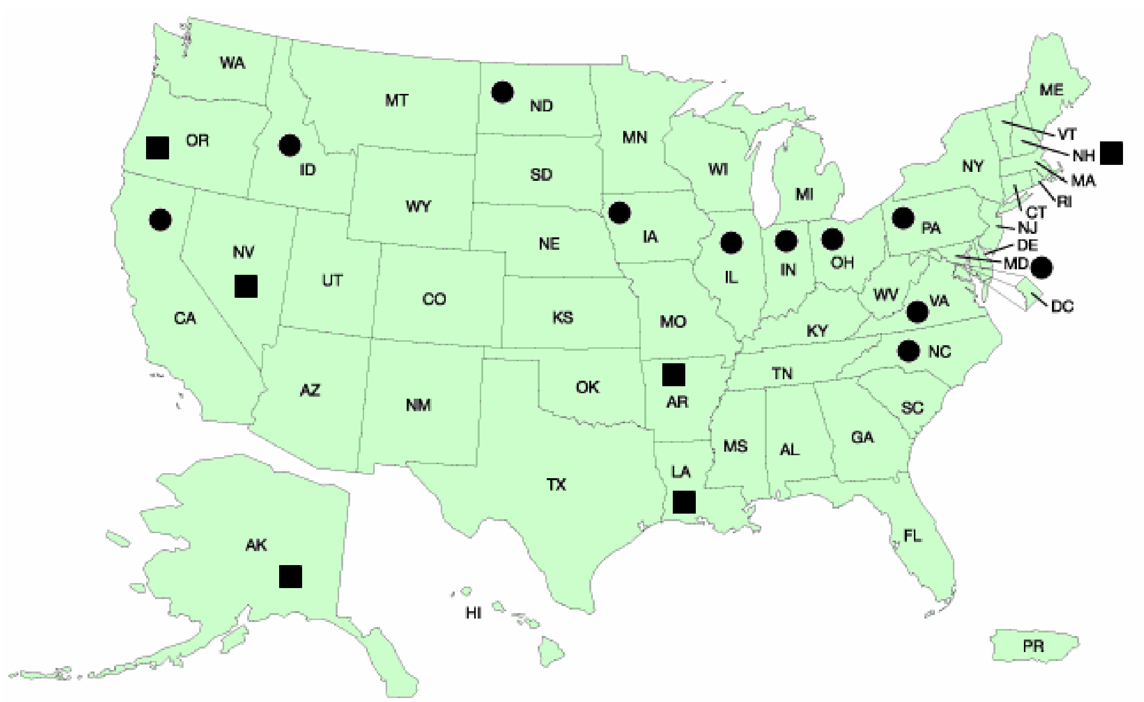


Figure 3.9: Establishment of Inspection Guidelines for Culverts – US DOTs.

● Yes ■ No ▲ Development Phase

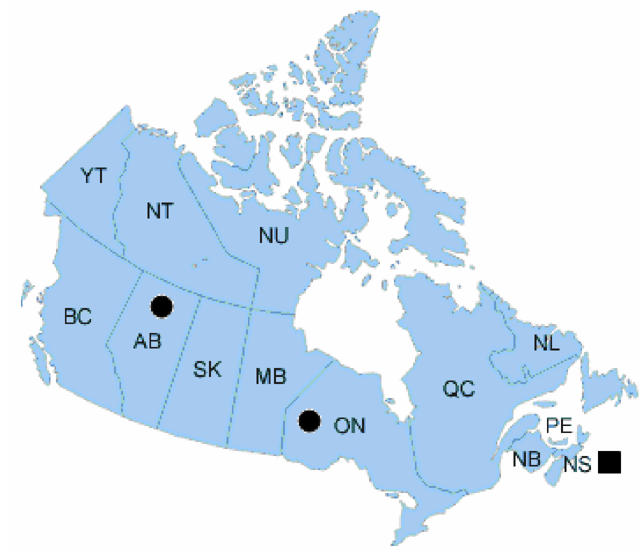


Figure 3.10: Establishment of Inspection Guidelines for Culverts – Canadian Provinces.

9. Which of the following are included in your inspection guidelines? (Drainage Inlet, Channel, Manholes, Junction Box, Headwall, Endwall, Wingwall, Footing and other components)

This question was framed to understand the importance given to the culvert components in the inspection guidelines. Not all components were included in the guidelines followed by different DOTs. Figure 3.11 shows the number (expressed in percentage) of DOTs including certain components in their inspection guidelines or manuals. Headwall, wingwall and endwall was given the highest importance followed by footings & channels, drainage inlet, junction box and finally manholes & other components.

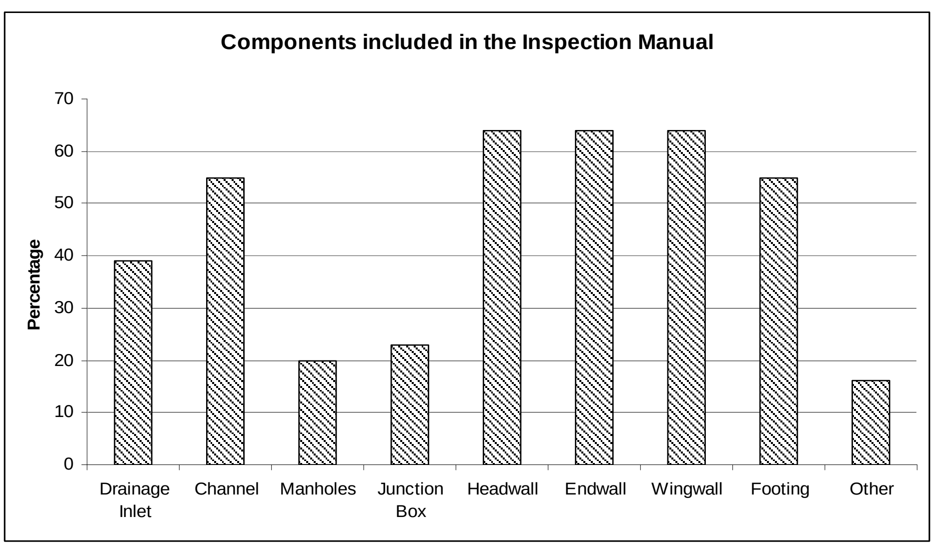


Figure 3.11: Graph Showing the Percentage Importance Given to Culvert Components in Inspection Guidelines and Manuals by DOTs.

10. Does your agency have an inspection manual?

This question was framed to check if the DOTs had compiled the culvert inspection guidelines in the form of a manual. This would allow us to go back to them and collect their guidelines, which would be helpful in framing our condition assessment inspection checklist. The response rate was 74%. According to Figure 3.12 and 3.13, twelve (12) DOTs had compiled their guidelines in the form of an inspection manual, eleven (11) DOTs had not compiled their guidelines in the form of a manual and two (2) DOTs were in the development stage of the manual.

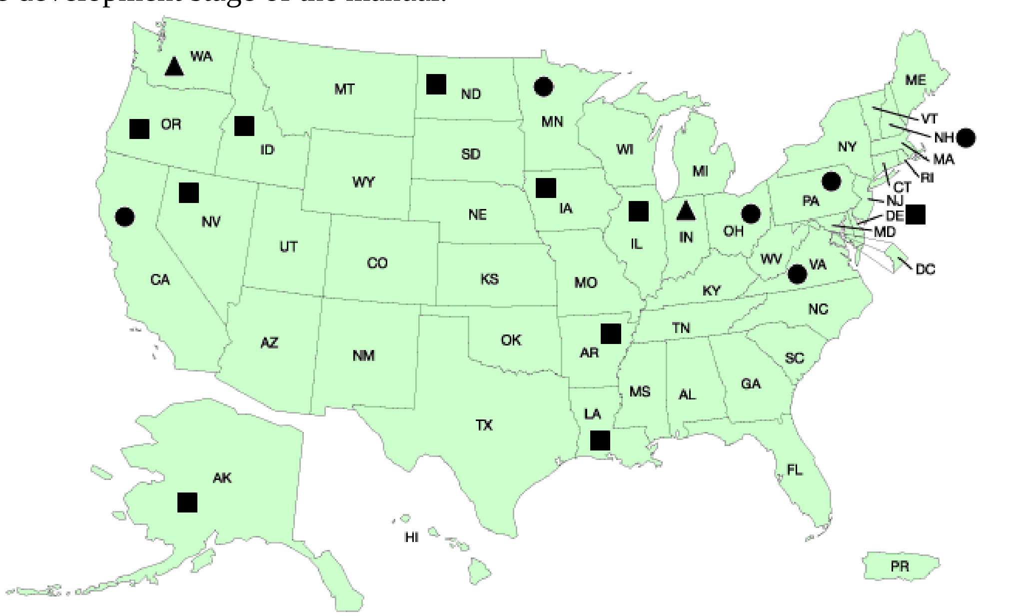


Figure 3.12: DOTs in U.S. Who Have Established a Culvert Inspection Manual.

● Yes ■ No ▲ Development Phase

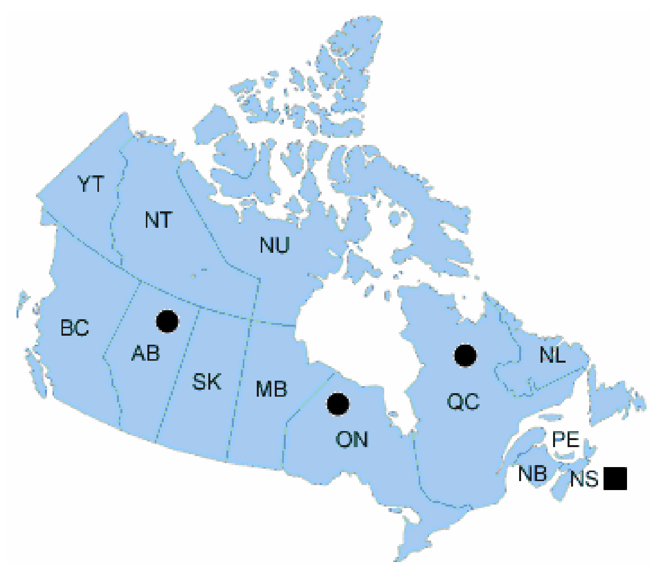


Figure 3.13: Canadian Provinces Who Have established a Culvert Inspection Manual.

11. Which of the following factors are considered in the inspection guidelines? Please rank the factors in the order of their importance – (Hydraulic capacity, Soil conditions, Joint Failures, Corrosion, Wall Thickness, Deflection and Cracking)

Twenty eight (28) DOTs responded to this question at a response rate of 82 %. All the DOT inspection guidelines had considered corrosion, joint failures and deflection; for metal culverts. Seventy eight (78) percent of the inspection guidelines had hydraulic capacity; seventy seven (77) percent had guidelines for cracking; sixty one (61) percent had soil conditions and fifty three (53) percent had wall thickness. Figure 3.14 shows the factors considered in inspection guidelines for concrete culverts.

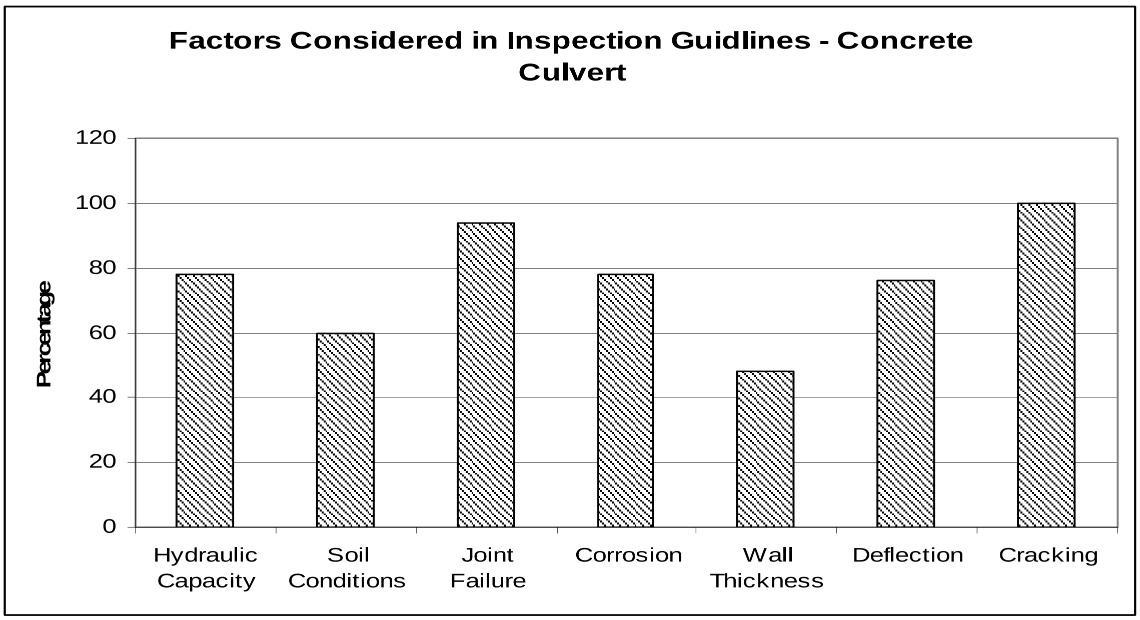


Figure 3.14: Factors Considered in Inspection Guidelines for Concrete Culverts.

Hydraulic capacity, joint failures, corrosion and deflection were ranked as very important. Cracking was given medium importance and soil conditions & wall thickness was considered as least important.

12. What factors are considered in replacing or renewing a culvert?

Structural, hydraulic and environmental factors play an important role in altering the condition of the culvert over a period of time. Regular inspection helps us in determining whether the culvert is in a good condition or needs renovation/replacement. This question is focused on determining the important factors considered by DOTs in deciding replacement or renovation of a culvert. According to the responders (Figure 3.15) structural problems (96%) were the most important factor followed by hydraulic problems (84%), material degradation (76%), deflection (68%), inspection results (64%), roadway surface (52%), age of culverts (40%), others (4%).

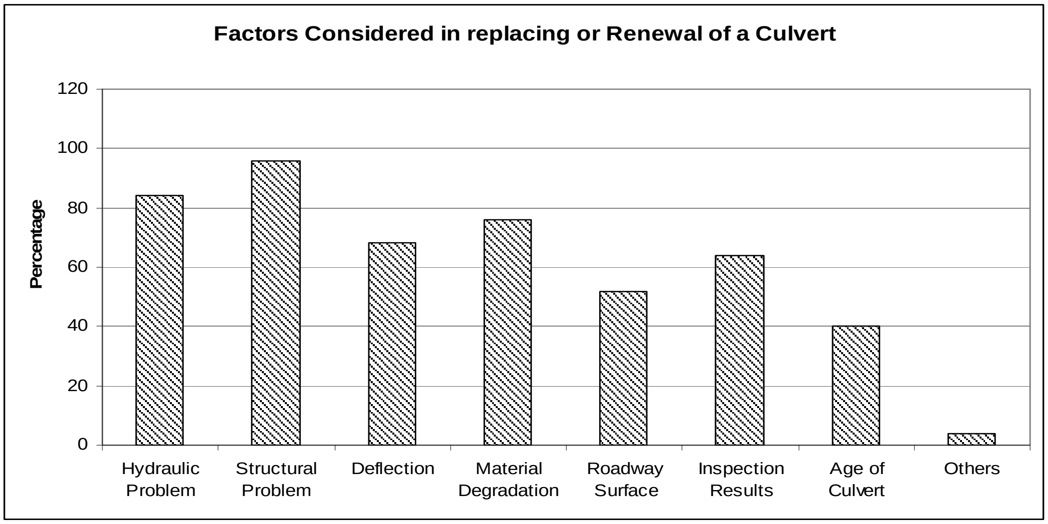


Figure 3.15: Factors Considered in Replacing or Renewing a Culvert.

13. Is there a model or formula your state uses in order to predict the remaining service life of culverts?

This question was to find out if any of the states had formulated a model to predict the remaining service life or useful life of culverts. Seventy eight percent (78%) of the respondents answered that they had no model to predict the service life of culverts, thirteen percent (13%) answered that they were developing some kind of model or formula. The state of Virginia has developed some kind of formula using statistical values with the help of American Mathematical Society (AMS) and Delaware uses Pontis Deterioration Models. Quebec uses a condition rating system to evaluate the service life of culverts.

14. Is it based on the condition assessment of culverts?

Sixty percent (60%) of the responses indicated that the relationship was based on condition assessment of culverts and ten percent (10%) said it was based on other relationship. Thirty percent (30%) of the responders said the relationship was under development stage.

15. Explain briefly how you overcome confined space problems while inspecting culverts

Confined space is one big obstacle in inspecting culverts. As per OSHA (Occupational Safety and Health Administration), entry will not be made into culvert:

- With a diameter/opening size of less than 18”
- Part of sanitary sewer system

- So lengthy that the coworker is unable to see the entrant
- Contain hazardous materials or substantial quantities of decaying organic material
- Require work which could create an atmospheric hazard
  (Safety Bulletin, NYSTD dated 2/03/03 available at https://www.nysdot.gov/portal/page/portal/divisions/operating/employee-health-safety/repository/culvertsbbg.pdf)

This question wanted to explore the different methods followed by DOTs in inspecting their culverts. Twenty six percent (26%) of the responses indicated that DOTs use CCTV to inspect and analyze the condition of their culverts, thirty five percent (35%) of the respondents answered that they inspect the inlets, outlets and other outer components of the culvert and inside is not inspected. Thirty-nine percent (39%) of the respondents use other methods. The states of Iowa, Maryland, Delaware and Washington monitor and test the oxygen content inside the culvert as per confined space guidelines. Idaho follows OSHA and MSHA (Mine safety and Health Administration) rules for larger culverts and do not inspect smaller culverts (less than 18 in.). Minnesota shoots video inside the culvert using a zoom camera. The province of Quebec either inspects from the ends of the culvert or uses a video camera depending upon dimensions and visibility.

16. What are the major structural or hydraulic culvert problems do you encounter in your culverts statewide?

Tables 3.3 and 3.4 present responses to this question.

Table 3.3: Structural Problems Encountered in Various States.

State	Structural Problems
Arkansas	Age of the culvert
Iowa	Joint failures, crack development
Louisiana	Invert corrosion/loss
Illinois	Deterioration of concrete walls and slabs
Nevada	Deterioration of CMP
Virginia	Scour, undermining, cracking, corrosion, settlement, concrete cracking and joints
Idaho	ASR for concrete, cracks, joint failure, scour damage, corrosion
California	Corrosion
Alaska	Embankment settlement & permafrost degradation
North Dakota	Sagging
Minnesota	Rusting, joint separation
Maryland	Deteriorating flowline
Delaware	Corrosion
Indiana	Deterioration of barrels due to rust and cracks
Ohio	Corrosion, deflection
Oregon	Crushed end sections

Table 3.4: Hydraulic Problems Encountered in Various States.

State	Hydraulic Problems
Arkansas	Age of culverts, sediments, debris
Iowa	Loss of hydraulic capacity
Louisiana	Siltation or loss of cross sections
Illinois	Scour/undermining
Nevada	Inadequate capacity
Virginia	Sedimentation and Debris accumulation
Idaho	Scour, debris buildup, improper size
California	Debris
Alaska	Beaver debris, waste fill, permafrost degradation
North Dakota	Erosion
Minnesota	Sediment deposits
Maryland	Unstable streambed material
Indiana	Insufficient opening, change in drainage area and blockage by debris
Ohio	Waterway adequacy, channel alignments, and scour
Washington	Abrasion, corrosion and debris accumulation
Ontario	Siltation, erosion downstream and occasional over stopping
Alberta	Undersized culverts
Nova Scotia	Loss of capacity due to debris, flooding during high intensity rainfalls

17. What are the major repair methods do you use for aforementioned problem?

Repair is the reconstruction of short pipe lengths, and not the reconstruction of whole culvert length to extend the design life of a culvert. Forty seven percent (47%) of the responses indicated that DOTs use point source repair, forty two (42%) grouting, and twenty six percent (26%) internal seal method for culvert structural and hydraulic problems. The other methods used by different states (37%) are as shown in Table 3.5.

Table 3.5: Culvert Repair Methods Followed in Various States.

State	Repair Methods
Iowa	Structural concrete, flowable mortar and cement grout
Virginia	Cleaning, joint repair, sleeving, replacement
Alaska	Trenchless technology methods
Minnesota	Pipe lining or jacking
Delaware	No repair, just replacement
Washington	Complete replacement
Quebec	Manual cleaning of culverts

18. What are the major renewal methods you use for problems listed in question 16? (Cured-In-Place Pipe, Sliplining, Pipe Bursting, Other)

Culvert renewal is the process of providing a new design life to the existing pipeline system. To address problems mentioned in question 16, sixty four percent (64%) of the respondents indicated that they would use sliplining methods to renew culverts, followed by cured-in-place pipe (CIPP) (18%) and pipe bursting (8%). Twenty three percent (23%) of the DOTs mentioned other types of renewal methods as listed in Table 3.6. Najafi (2005) provides more information on sliplining, CIPP, pipe bursting as well as other trenchless renewal methods.

Table 3.6: Other Culvert Renewal Methods Used.

State	Renewal Method
Louisiana	Culvert Replacement (trenchless and open-cut)
Virginia	Sleeving (a form of sliplining method)
Idaho	Spot Repairs

19 and 20. Does your culvert have a computer database inventory and what software do you use?

The objective of this question is to determine if there is any artificial intelligence systems being applied/used in DOTs to track and monitor culverts. Fifty-two percent (52%) of the respondents said they had some kind of tracking and monitoring system for culverts and nineteen percent (19%) of DOTs are developing some kind of model or system to track the culverts. The state of Virginia uses HTRIS, PONTIS and ORACLE for managing their culverts, Idaho and Delaware use PONTIS, California stores all their culvert information in MS ACCESS, Alaska, Indiana, Ohio and Alberta have their own in-house software and Ontario has OBMS in Visual Basic software.

21. Do you have a Decision Support System (DSS) for selection of a specific method for renewal or repair or renewal of old and deteriorated culverts?

A Decision Support System (DSS) is a computerized system for making decisions among available alternatives based on estimates of the values of those alternatives. Managing hundreds of thousands of culverts is a challenging task and needs a good DSS designed as a part of state asset management program. As Figures 3.16 and 3.17 illustrate, twenty three (23) DOTs responded to this question and eighty three percent (83%) of the respondents stated they had no DSS for culverts. Thirteen percent (13%) said they had some kind of DSS and four percent (4%) of the respondents were in the development stage. The state of Virginia uses a decision model based on the statistically generated condition data from RCA (Random Condition Assessment).

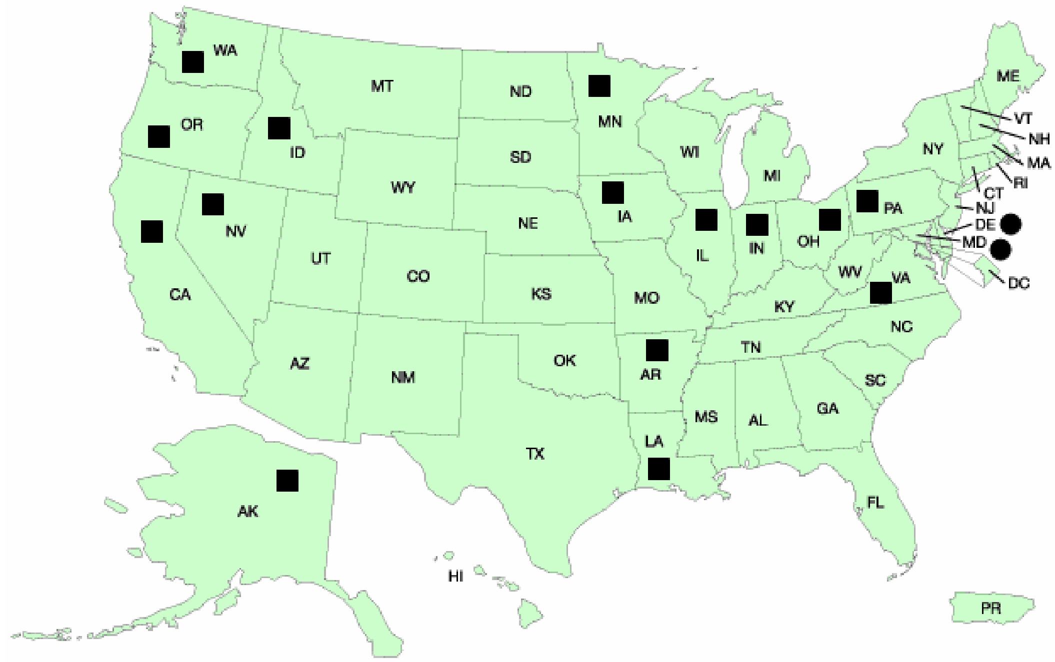


Figure 3.16: USDOT's having DSS

● Yes ■ No ▲ Development Phase

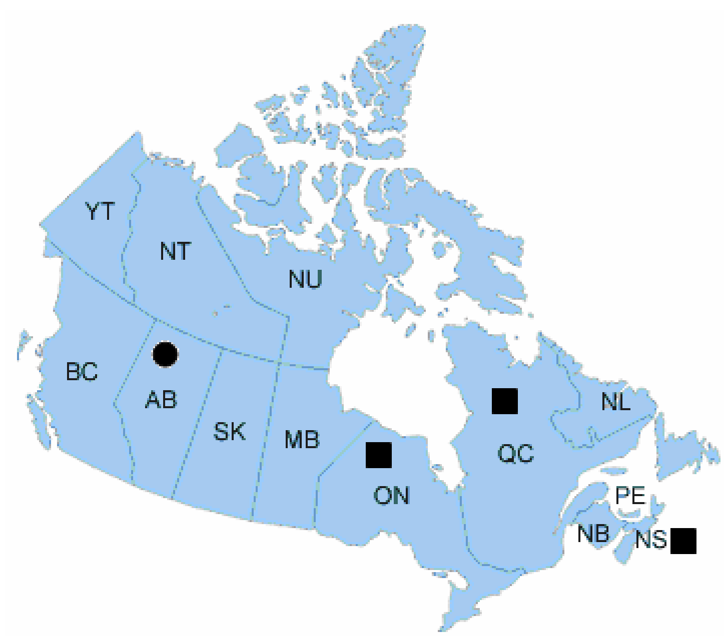


Figure 3.17: Canadian Provinces having DSS.

22. Do you have a model for integrating culvert inventory and condition assessment to predict the life cycle performance of culvert?

Life cycle performance of a culvert is a factor to determine the remaining service life of a culvert. The inventory data and the condition assessment results can be used as inputs to determine the performance factor. The question was an attempt to understand if any of the DOTs had an artificial intelligence or formula to determine the performance of culverts. A total of sixty two percent (62%) responded to this question. As per Figures 3.18 and 3.19, sixty seven percent (67%) of the respondents indicated that they had no model to determine the performance of culverts. Nineteen percent (19%) of the DOTs had some model to determine the culvert performance. The states of Virginia and Delaware use PONTIS to assess culvert performance. The province of Quebec integrates the anticipated repair or renewal timeframe with culvert condition rating to determine remaining life (in years) of culverts.

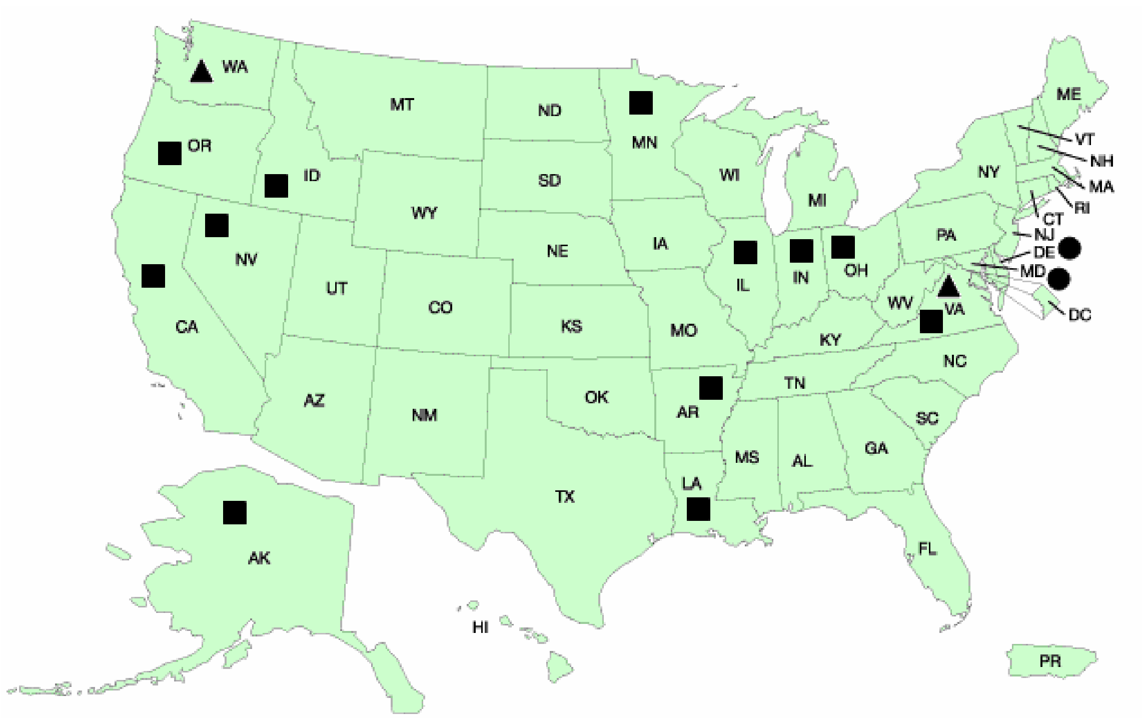


Figure 3.18: USDOT's having a Model to Determine Culvert Performance Factor.

● Yes ■ No ▲ Development Phase

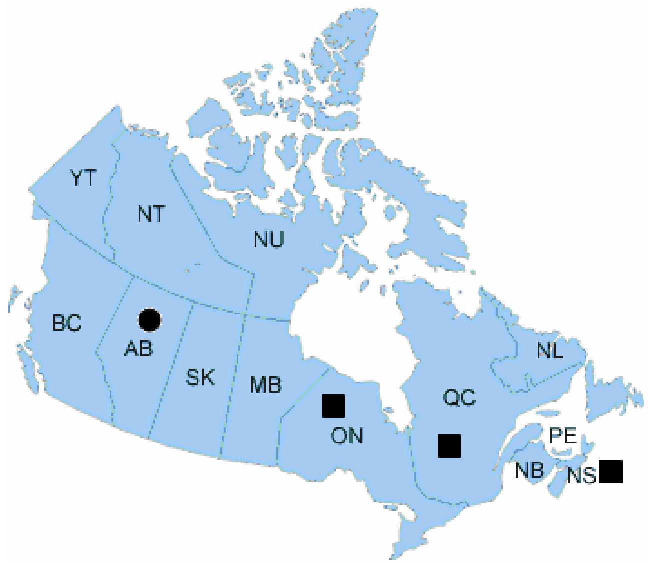


Figure 3.19: Canadian Provinces Having a Model to Determine Culvert Performance Factor.

23. How do you rate the importance of culvert asset management in your state?

The response rate to this question was sixty eight percent (68%). The rating system was –

7 – 9 = Very important
3 – 6 = Important
Less than 3 = Not so important

As per Figure 3.20, thirty percent (30%) of the DOTs responded that culvert asset management was very important (rating – 7), seventeen percent (17%) responded as important (rating 5) and four percent (4%) as not so important (rating – 3). Figures 3.21 and 3.22 show the rating system for different states and provinces in US and Canada, respectively.

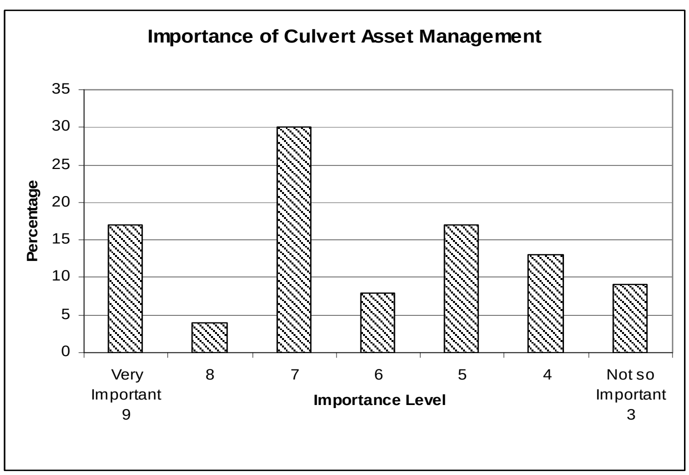


Figure 3.20: Graph indicating the Culvert Asset Management Importance Rating System.

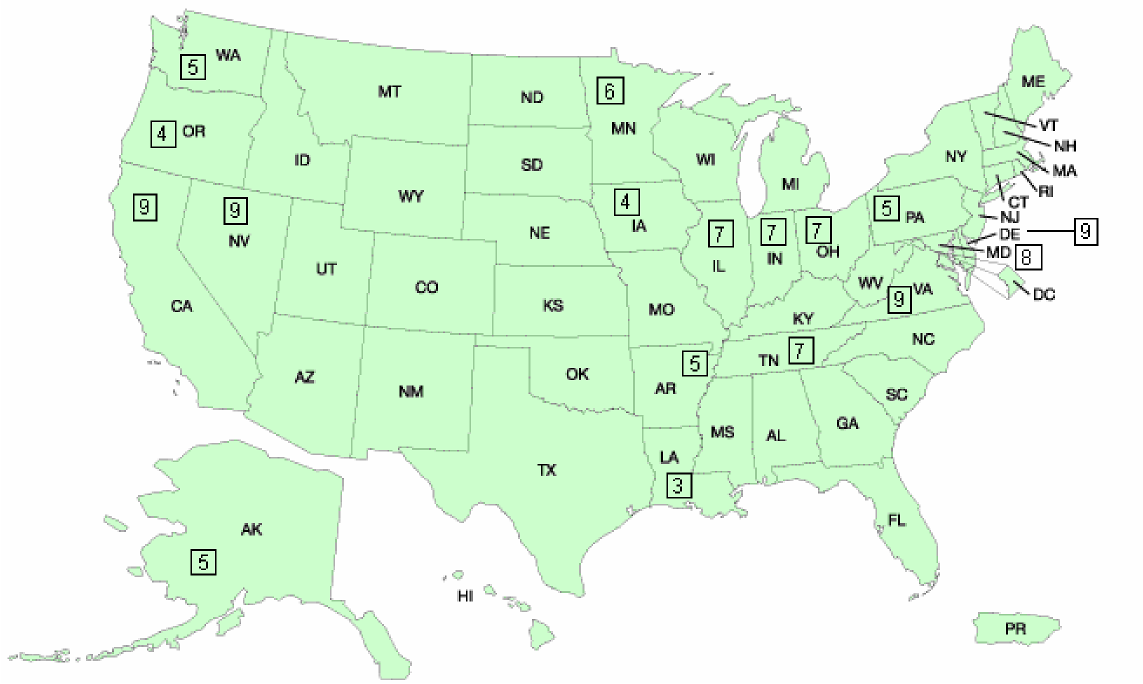


Figure 3.21: Culvert Asset Management Importance Rating System in US.

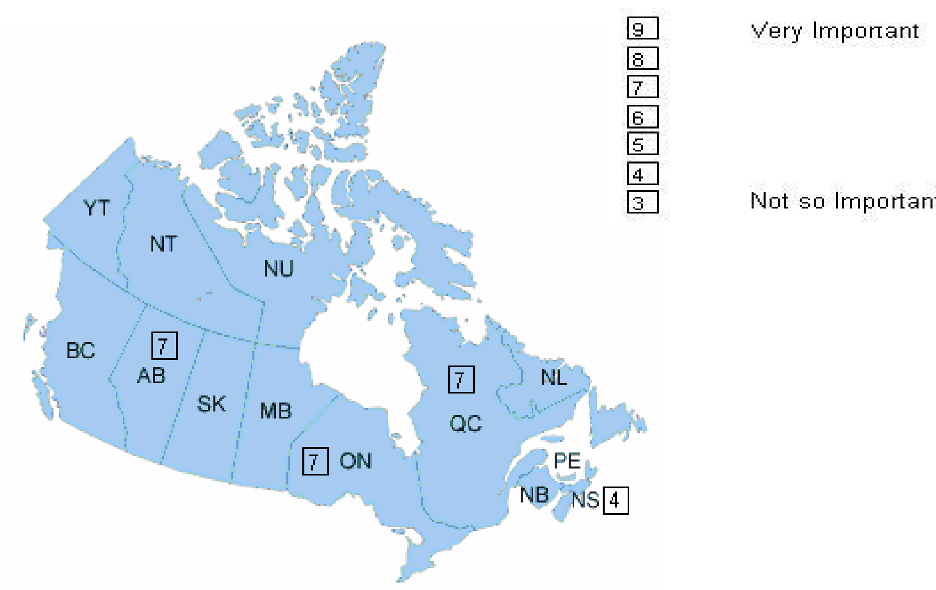


Figure 3.22: Culvert Asset Management Importance Rating System in Canada.

3.4 Chapter Summary

Culvert asset management is a relatively new concept in the U.S.A. and Canada. The awareness to implement culvert asset management in every state is growing due to increasing number of culvert collapses and failures. The survey presented in this chapter, indicated that eighty one (81%) of the DOTs *feel* that their culverts are in good condition. This is the right time for DOTs to track and maintain a good database of culverts with their condition information to avoid future disasters. We also understood from the survey that some DOTs currently have some form of guidelines to track and inspect large culverts (opening 3-ft or above). Most of culverts are designed for 50-year flood and are inspected every 2-5 years. Most culverts are repaired or renewed due to structural and hydraulic problems, of which, hydraulic capacity, corrosion, joint failures, and cracking are rated high. PONTIS is the most commonly used software used to track culverts. None of the states have developed a good decision support system, which monitors tracking, inspection and suggests necessary repair or renewal methods based on the extent of the damage. Thirty percent (30%) of the respondents rated culvert asset management as a very important concept in preserving our deteriorating infrastructure.

CHAPTER 4.0

CULVERT INVENTORY AND INSPECTION PRACTICES IN OHIO

4.1 Introduction

Due to the aging highway network in the United States, highway elements, which are in need of repair and renewal works, are increasing in great numbers. Culverts and drainage structures are among these crucial elements. The necessity of a comprehensive database that includes the inventory and condition information of each culvert within a drainage network is becoming more obvious as transportation officials are trying to cope with the fast deterioration rate of culverts. As it was mentioned in the previous chapters, most of the DOTs lack an integrated efficiently working culvert inventory and condition database.

Inspecting an enormous number of culverts can be an expensive undertaking especially if this inspection does not fully serve to establish a reliable inventory and condition database. The level of information and detail that is being sought and the experience of the inspector may play a vital role in the efficiency of inspections. Providing inspectors with a detailed explanation of the inspection procedures through an inspection manual is helpful in standardizing the inspection work in different areas of the network and establishing a reliable and integrated database. Therefore, developing an inspection manual is one of the keys to having an efficient culvert asset management strategy. In this section, the culvert management manual, which was published by Ohio Department of Transportation in 2003, is going to be covered. This section will serve as a review of the existing culvert inventory and inspection procedures suggested by the ODOT Culvert Management Manual.

4.2 ODOT Culvert Management Manual

Culverts have been among important assets of highway elements for Ohio Department of Transportation. Large number of publications and research projects initiated in Ohio enabled ODOT to compile their experience and knowledge in a management manual, namely Culvert Management Manual, which was published in 2003. The objective of this manual is given as “to provide a tool for the inventory, periodic inspection, and maintenance of culverts, and structures with less than a 10 foot span”. In this manual two important forms, culvert inventory form (CR-87) and culvert inspection form (CR-86), are introduced and detailed explanations for each of the items in these forms are provided. Therefore, Culvert Management Manual can be divided into two parts as culvert inventory and culvert inspection.

4.2.1 Culvert Inventory

Culvert inventory form is used by ODOT to add a newly constructed culvert to the database, to remove a retiring culvert from the database, or to modify the information on the base whenever changes have been made to the existing culvert. This inventory consists of culverts owned or maintained by the department and having a span or diameter of 12 inches or greater and storm sewers passing under the traveled lanes with a span or diameter of 36 inches or greater.

4.2.1.1 Culvert Inventory Form (CR-87) (See Appendix 7)

CR-87 starts with entering the culvert file number (CFN) of the culvert for which the inventory form is being filled. CFN is a 9-digit unique number defined for each culvert and changes only if the culvert is replaced. The breakdown of CFN is as follows:

County Number	2 digits	2 digit county code from the table
Route	3 digits	Main route number
Culvert Number	4 digits	randomly selected number, not currently used

Item 1. Entry Class

Entry class depends on various factors, which may affect the safety of inspectors. There are four different entry class types, which are shown in Table 4.1:

Table 4.1: Entry Class Types (ODOT, 2003).

Code	Description
A	Class A – Non-entry Inspection
B	Class B – Non-Permit Required Entry
C	Class C – Alternate Entry Permit Required
D	Class D – Permit Required

Location and Route Information:

There are 9 items under that category, which are used to provide location and route information. These items are shown in Table 4.2.

Table 4.2: Location and Route Information Items (ODOT, 2003).

Item	Characteristics	Identification
Item 2	District	2 digit district code
Item 3	County	3 letter county abbreviation

Item	Characteristics	Identification
Item 4	Route	Route Number
Item 5	Straight Line Mileage	4 character number representing the distance
Item 6	Latitude	XX degrees XX minutes XX.XX seconds
Item 7	Longitude	XX degrees XX minutes XX.XX seconds
Item 8	Road ID	1 Side Road Left 2 Side Road Right 3 Left Lanes of Divided Highway 4 Right Lanes of Divided Highway 5 Ramp to the Left 6 Ramp to the Right 7 Pipe Abandoned but still in place Blank Mainline
Item 9	Maintenance responsibility	S State DOT C County Agency T Township M City or Municipality N Department of Natural Resources O Other
Item 10	Feature Intersection	Name of feature intersected by the culvert

Culvert
Items 11 through 29 are used to gather necessary inventory data for the culvert structure.

Item 11: Year Built: The actual year of installation should be entered without abbreviations. If the actual year is unknown, UUUU should be entered.

Item 12: Number of cells: The number of cells of the culvert should be entered.

Item 13: Shape: The appropriate code should be selected by using Table 4.3.

Table 4.3: Shape Codes (ODOT, 2003).

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

Item 14: Material: The appropriate code should be selected by using Table 4.4.

Table 4.4: Material Codes (ODOT, 2003**).**

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	Corrugated Stainless Steel, Non-sectional Plate
08	Corrugated Stainless Steel, Sectional Plate
09	Corrugated Aluminum Alloy
10	Brick
11	Field Tile (Clay)
12	Corrugated Plastic
13	Corrugated Plastic Smooth Interior
14	Steel Casing
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

Item 15: Span: Distance between the inside faces of the barrel. If adjacent barrels are less than half a diameter of the smaller barrel apart from each other, multiple cells should be considered as one structure.

Item 16: Rise: Maximum rise should be recorded to nearest inch.

Item 17: Length: The length of the culvert from inlet to outlet should be recorded.

Item 18: Gage / Wall Thickness: The appropriate code should be selected by using Table 4.5.

Table 4.5: Gage / Wall Thickness Codes (ODOT, 2003)

Gage	Inches	mm
16	0.064	1.63
14	0.079	2.01
12	0.109	2.77
10	0.138	3.51
8	0.168	4.27
7	0.188	4.78
5	0.218	5.54
3	0.249	6.32
1	0.28	7.11

Item 19: Gage / Wall Thickness: If there are multiple gage thicknesses, the second gage should be entered otherwise it should be left blank.

Item 20: Type of Protection: The appropriate code should be selected by using Table 4.6.

Table 4.6: Protection Type Codes (ODOT, 2003).

Code	Description
1	Unprotected
2	Galvanized
3	Half Bituminous Coated
4	Fully Bituminous Coated
5	Half Bituminous Coated and Paved
6	Fully Bituminous Coated and Paved
7	Asbestos Bond Coated
8	Asbestos Bond Coated and Paved
9	Vitrified Lined
10	Field Paved
11	Coal Tar Resin
12	Thermoplastic Coated
13	Aluminum Coated
99	Special Item not Listed

Item 21: Slope of the pipe: The slope should be calculated and recorded by using the following formula:

$$\text{Slope} = (\text{Fall} / \text{Length}) * 100$$

Item 22: Skew: Skew of the culvert should be recorded to the nearest degree.

Items 23 and 24: Inlet and Outlet End Treatment: The appropriate code should be selected by using Table 4.7.

Table 4.7: Inlet and outlet treatment codes (ODOT, 2003).

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

Item 25: Maximum Height of Cover: The maximum distance between the top of conduit and the pavement or embankment surface should be measured and recorded.

Item 26: Modification Type: The appropriate code should be selected by using Table 4.8.

Table 4.8: Modification type codes (ODOT, 2003).

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

Item 27: Year Modified: The year in which the culvert had a major repair or renewal should be recorded.

Item 28: Modification Material: The appropriate code should be selected by using Table 4.9.

Table 4.9: Modification Material Codes (ODOT, 2003).

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

Item 29: Modification size: The size of the modification depending on the modification type should be recorded. The measurements to be recorded should be selected by using Table 4.10:

Table 4.10: Modification Size Measurements (ODOT, 2003).

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 joints or other areas	Internal diameter at bands

Extension Inlet

In Items 30 – 36 information, regarding the extension at the inlet (if applicable) should be recorded. These items are year extended, shape, material, span, rise, gage/wall thickness and extension length respectively.

Extension Outlet

In Items 37 – 43 information, regarding the extension at the outlet (if applicable) should be recorded. These items are year extended, shape, material, span, rise, gage/wall thickness and extension length respectively.

Hydrology / Hydraulics

Item 44: Drainage Area: Drainage area of the culvert should be recorded in acres.

Item 45: Design Discharge: Design discharge value for the culvert should be recorded (ft^3/sec).

Item 46: Abrasive Conditions: Presence of granular material should be recorded as Y for abrasiveness and if granular material is not present, N for no abrasiveness should be recorded.

Item 47: pH: pH value of the stream at the inlet should be recorded. If field-testing is not possible at the time of inspection, pH data from the plans should be used.

Items 48 and 49: Channel Protection (Inlet and Outlet): The appropriate code should be selected by using Table 4.11.

Table 4.11: Channel Protection Codes (ODOT, 2003).

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 Blocks
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

Comment Section: Any issue related to the culvert, which was not addressed in these items, should be entered by the field official in the comments section.

4.2.2 Culvert Inspection

Culvert inspections are performed to verify the condition of the culverts and to make decisions on the necessary maintenance, repair, renewal or replacement works. According to Ohio Department of Transportation's Culvert Management Manual, there are five different types of culvert inspections, namely, Inventory Inspection, Routine Inspection, Damage Inspection, Interim Inspection and Storm Sewer Inspection.

Inventory inspection is the first inspection of a culvert once it has been constructed. Inventory inspection is also applied whenever there has been a change in the configuration of the structure.

Routine inspection is performed according to a regular schedule. The main objectives of a routine inspection include identifying the physical and functional condition of the culvert and identifying the future problems, which might be probable to occur.

Damage inspections are performed on an unscheduled basis due to occurrence of damaging floods and/or storms. The objectives of this type of inspection include the assessment of necessary repair work and identifying the necessity of load restrictions or traffic closures.

Interim inspections are performed at the discretion of the individual responsible for culvert inspection. It can be performed by any qualified person who has knowledge about culverts.

Storm sewer inspections are the application of inventory and routine inspections to the storm sewers.

The frequency of inspections is determined in the ODOT Culvert Manual is listed in the Table 4.12.

Table 4.12: Frequency of Inspections (ODOT, 2003).

Description	Frequency of Inspection	Type of Inspections
12" ≤ Diameter / Span ≤ 120"	5	Routine
Storm Sewers, Diameter ≥36"	5	Routine, storm sewer
Culverts and Storm Sewers with known defects	Determined by culvert inspection reviewer or bridge engineer	Damage, interim

The inspection procedure for a particular culvert should start with examining the available information. Required safety precautions should also be reviewed. The general overall condition of the culvert and the approach roadway should be examined. The embankment, end treatment structures and the culvert barrel should be examined from the outlet and the procedure should be repeated for the inlet.

There are various techniques which can be used to inspect an existing culvert are explained in Appendix 9.

4.2.2.1 Culvert Inspection Form (CR-86) (See Appendix 7)

Item 1. General: In this item, the culvert should be evaluated for the deterioration of barrel material or footing, cracks and dents and localized damage.

Depending on the culvert material, the inspector should use the appropriate table among Tables 4.13, 4.14, 4.15, 4.16 for evaluating the general rating of the culvert.

Corrugated Metal Culvert:

Table 4.13: General Rating Codes for Corrugated Metal Culverts (ODOT, 2003).

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. 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 Failure	Pipe partially collapsed.
0	Failed	Total Failure of Pipe

Concrete Culvert:

Table 4.14: General Rating Codes for Concrete Culverts (ODOT, 2003).

Code	Category	Description
9	Excellent	New Condition, Superficial and isolated damage from construction.
8	Very Good	Hairline cracking without rust staining or delamination; surface in good condition isolated damage from 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 in.) on 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 1/4 inch deep. Spalled areas with exposed reinforcing less than 5%. Additional Delaminated/Spalled areas less 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 in. 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 1/2 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 3/4 inch. (approximately 50% of culvert is affected)
3	Serious	Extensive cracking with spalling, delamination, and slight differential movement; scaling has exposed all surfaces of the reinforcing steel in bottom to top slab or invert (approximately all exposed surfaces are 50% loss of wall thickness at invert; concrete very soft
2	Critical	Full depth holes. Extensive cracking greater than 1/2 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 is completely exposed.

1	Imminent Failure	Culvert partially collapsed or collapse is imminent.
0	Failed	Culvert is collapsed

Masonry Culvert:

Table 4.15: General Rating Codes for Masonry Culverts (ODOT, 2003).

Code	Category	Description
9	Excellent	New condition
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 units
3	Serious	Extensive cracking with spalling, delamination, 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.

Plastic Culverts:

Table 4.16: General Rating Codes for Plastic Culverts (ODOT, 2003).

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 inch) at two or three locations. Damage (Cuts, gouges, burnt edges, or distortion) to end sections from construction or maintenance. Perforations caused by abrasion located with 5 feet of inlet and outlet and not

Code	Category	Description
		located under roadway.
5	Fair	Split (larger than 6 inches, width exceeding ½ inches) at two or three locations. Damage (Cuts, gouges, or distortion) to end sections from construction or maintenance. Perforations caused by abrasion located with 5 feet of inlet and outlet and not located under roadway. Fire damage beneath roadway causing distortion greater than 18 in. in diameter.
4	Poor	Split (larger than 6 inches, width exceeding ½ in.) several locations. Split causing loses of backfill material. Perforations caused by abrasion located throughout pipe. Fire damage beneath roadway causing holes greater than 6 inch in diameter.
3	Serious	Split (larger than 6 inches, width exceeding 1 in.) several locations. Split causing loses of backfill material. Section loses caused by abrasion located throughout pipe. Fire damage beneath roadway causing holes greater than 12 inches in diameter.
2	Critical	Invert eroded away (with section 2 feet 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.

Item 2. Culvert Alignment: Inspector should examine the longitudinal irregularities of the culvert. Depending on the material type, the inspector should use either Table 4.17 or Table 4.18 to determine the appropriate rating for culvert alignment.

Concrete, Corrugated Metal and Plastic Culverts:

Table 4.17: Culvert Alignment Rating Codes for Concrete, Corrugated Metal and Plastic Culverts (ODOT, 2003).

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 1/2 in. no fill no settlement. Minor settlement or misalignment, Ponding less than 3 inches.
6	Satisfactory	Fair, minor misalignment and settlement at isolated locations. Moderate settlement or misalignment, Ponding between 3 and 5 inches.
5	Fair	Minor misalignment or settlement throughout culvert. Ponding (depths 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.

Code	Category	Description
4	Poor	Significant settlement and misalignment of pipe. Significant Ponding (depths less than 6 inches) of water due to sagging or misalignment of pipes sections, end sections dislocated 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 pipes sections, end section drop off has occurred. Four or more sections with off sets greater than 4 inches.
2	Critical	Culvert not functioning due to alignment problems throughout
1	Imminent Failure	Culvert partially collapsed or collapse is imminent.
0	Failed	Culvert collapsed

Masonry Culverts:

Table 4.18: Culvert Alignment Rating Codes for Masonry Culverts (ODOT, 2003).

Code	Category	Description
9	Excellent	New Condition
8	Very Good	Straight lines 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

Item 3. Shape: This item is only applicable to flexible culverts since rigid culverts do not show considerable deflection before cracking. For the long span metal pipe culverts, the area between 2 o'clock and 10 o'clock is important.

For arch type culverts, sides should be checked for flattening and crown should be checked for peaking. In corrugated metal box culverts, top arc should be checked for flattening and the sides should be checked for inward/outward movement. Plastic pipes should be checked for deflection and buckling. Inspector should choose the appropriate code by using either Table 4.19 or Table 4.20 depending on the material type.

Corrugated Metal Culverts

Table 4.19: Shape Rating Codes for Corrugated Metal Culverts (ODOT, 2003)

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 percent of design
7	Good	Top half of pipe smooth but minor flattening of bottom; span dimension within 2.5 percent of design
6	Satisfactory	Smooth curvature in top half, bottom flat, span dimension up to 5 percent 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 percent 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 percent 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 percent greater than design. Extreme non-symmetric shape
2	Critical	Critical, extreme distortion and deflection throughout pipe; span dimension more than 20 percent greater than design critical
1	Imminent Failure	Structure partially collapsed with crown in reverse curve
0	Failed	Structure collapsed

Plastic Pipe Culverts:

Table 4.20: Shape Rating Codes for Plastic Culverts (ODOT, 2003)

Code	Category	Description
9	Excellent	Smooth wall, deflection less than one 2% from 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 in. deep. Pipe deflection less than 10% from original shape
5	Fair	Minor dimpling appearing over 1/16 to 1/8 of circumference area and 2 feet in length. Dimples between 1/4 and 1/2 in. deep. Pipe deflection less than 12.5 percent from original shape.
4	Poor	Wall Crushing or hinging occurring with lengths less than 3 feet. Pipe deflection less than 15% from original shape.

Code	Category	Description
3	Serious	Wall Crushing or hinging occurring with lengths greater than 3 feet. Moderate degree of dimpling appearing. Dimples more than 1/2 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 1/2 inch deep. Wall tearing/cracking in the buckled region. Pipe deflection greater than 20% from original shape. Severe dimpling accompanied with wall splits.
1	Imminent Failure	Pipe partially collapsed or collapse is imminent.
0	Failed	Total failure of pipe.

Item 4. Seams or Joints: Seams and joints should be checked against soil infiltration and water exfiltration. The inspector should use either Table 4.21 or Table 4.22 depending on the culvert type in order to select the appropriate rating code for the seams and joints.

Corrugated Metal, Multi-Plate

Table 4.21: Seam Rating Codes for Multi-Plate Corrugated Metal Culverts (ODOT, 2003)

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 bolthole 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 bolts 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.

Corrugated Metal, Concrete, Plastic Pipe, and Masonry Culverts

Table 4.22: Joint Rating Codes for Corrugated Metal, Concrete, Plastic Pipe, and Masonry Culverts (ODOT, 2003).

Code	Category	Description
9	Excellent	Straight line between sections.
8	Very Good	No settlement or misalignment; Tight with no defects apparent
7	Good	Minor misalignment at joints; off sets less than 1/2 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 to alignment problems throughout. Large voids seen in fill through offset joint
1	Imminent Failure	Pipe partially collapsed or collapse is imminent.
0	Failed	Total failure of pipe.

Item 5. Slab: Slabs should be checked for deterioration, leakage and structural adequacy. Inspection of slabs is important due to their load carrying nature. Inspector should use Table 4.23 in order to select the appropriate rating for slabs.

Table 4.23: Slab Rating Codes (ODOT, 2003).

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 delamination; 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. Note: Slab may have a single large crack (less than 3/16 in.) on bottom surface parallel to the direction of traffic
6	Satisfactory	Transverse cracks evident on bottom side (spacing 10 ft to 20 ft), 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 traffic 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 (not 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 in. 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 effloresces 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 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 (not including slab edges).
3	Serious	Same as “Poor” description except: Included in distressed 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 of concrete areas are greater than 50% of surface area. Reinforcing steel bars have extensive

Code	Category	Description
		section losses (greater than 30% of original diameter) for more than 10 adjacent bars. Included in distressed areas reinforcing steel 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

Item 6. Abutment: Abutments should be checked against movement, material problems, scouring and settlement. Inspector should use either Table 4.24 or Table 4.25 depending on the material type in order to select the appropriate rating for abutments.

Concrete:

Table 4.24: Abutment Rating Codes for Concrete Culverts (ODOT, 2003).

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 delamination 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. Note: abutment may have a single vertical large crack (less than 3/16 inch).
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

Code	Category	Description
		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 than 1/4 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 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.
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

Masonry

Table 4.25: Abutment Rating Codes for Masonry Culverts (ODOT, 2003).

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 areas 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.

Code	Category	Description
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

Item 7: Headwalls: Headwalls, endwalls or wingwalls may have a significant effect on the culver performance. They should be checked for deterioration, settlement, undercutting and other signs of failure. Inspector should use Table 4.26 in order to select the appropriate rating for headwalls.

Headwalls

Table 4.26: Headwall Rating Codes (ODOT, 2003).

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 delamination 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 in. 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

Code	Category	Description
		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 away 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 in. 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 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

Item 8. End Structure: Catch basins, inlets, manholes, junction chambers and other end structures should be checked against structural and connection problems. Inspector should use Table 4.27 in order to select the appropriate rating for end structures.

Table 4.27: End Structure Rating Codes (ODOT, 2003).

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 delamination 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

Code	Category	Description
		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 %). 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 in. 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 in. with efflorescence and rust staining. Spalling at numerous locations; extensive surface scaling greater than 1/2 in. 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-in. 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.

Channel:

Item 9. Channel Alignment: Channel alignment should be checked whether it is causing any adverse conditions to the culvert or channel protection. Inspector should use Table 4.28 in order to select the appropriate rating for channel alignment.

Table 4.28: Channel Alignment Rating Codes (ODOT, 2003).

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 brush growing in the channel.
6	Satisfactory	Flows through 1 out of 2 pipes; Flows along one abut. Does not flow under center of the culvert, minor curve (20o-40o 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 40o-50o) Trees and brush 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 50o-70o) Flow enters pipe by other means than designed opening.
3	Serious	80-90 degree 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. The waterway 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.

Item 10. Protection: Channel protection is used to protect the channel banks from scour. Inspector should use Table 4.29 in order to select the appropriate rating for channel protection.

Table 4.29: Channel Protection Rating Codes (ODOT, 2003).

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.

Item 11. Culvert Waterway Blockage: Any obstruction such as debris or sandbars, which would affect the adequacy of water conveyance, should be checked. Inspector should use Table 4.30 in order to select the appropriate rating for waterway blockage condition.

Table 4.30: Culvert Waterway Blockage Rating Codes (ODOT, 2003).

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.

Code	Category	Description
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.

Item 12. Scour: Scouring may cause problems at the end sections of the culvert, which may lead to flow restrictions. In culverts without invert slabs inspectors should check for the erosion of the streambed and footing problems and select the appropriate rating for scouring by using Table 4.31:

Table 4.31: Scour Rating Codes (ODOT, 2003).

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

Approaches:

Item 13. Pavement: Inspector should use Table 4.32 in order to select the appropriate rating for pavement.

Table 4.32: Pavement Rating Codes (ODOT, 2003).

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 minor 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, impassable.

Item 14. Guardrail: Alignment of guardrails may provide information about a possible settlement or embankment problem. The inspector should use Table 4.33 in order to determine the appropriate condition of the guardrails.

Table 4.33: Guardrail Rating Codes (ODOT, 2003).

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. Poor 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.
2	Critical	Guardrail is no longer functioning; Major decay of post (90%)

Code	Category	Description
1	Imminent Failure	Guardrail partially collapsed
0	Failed	Total failure guardrail

Item 15. Embankment: Embankments should be examined against settlement, bulging, slide failures and erosion. The inspector should use Table 4.34 in order to determine the appropriate condition of the embankment.

Table 4.34: Embankment Rating Codes (ODOT, 2003).

Code	Category	Description
9	Excellent	No noteworthy deficiencies which affect the condition of the embankment up to 100 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.

Item 16. Level of Inspection: The inspector should enter the appropriate code for the level of inspection using Table 4.35.

Table 4.35: Level of Inspection Codes (ODOT, 2003).

Code	Description
X	Inspection from ends of culvert. (Non-entry)
M	Manned Entry inspection
V	Video inspection

General:

General Appraisal: The culvert should be compared to its initial as-built condition and the operational status code should be selected from Table 4.36.

Table 4.36: General Appraisal Codes (ODOT, 2003).

Code	Description
9	As built condition
8	Very good condition - no problems noted
7	Good condition - some minor problems
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

Operational Status: The operational status of the culvert should be entered by using Table 4.37.

Table 4.37: Operational Status Codes (ODOT, 2003).

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 renewal
G	New structure not yet open 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

4.3 Chapter Summary

Ohio Department of Transportation's Culvert Management Manual provides the field engineers a detailed guideline for inventory and inspection of culverts. The manual includes the necessary information to be recorded when a structure is constructed or replaced and the required steps to be followed during an inspection mission.

The ODOT Culvert Management Manual’s inspection and rating procedures were tested in a study, which is published recently after the publication of the manual (Mitchell et. al., 2005). According to the results of this study, the ODOT Culvert Management Manual’s inspection and rating systems were reported as “basically sound.” Therefore this manual provides valuable information for agencies which are at the development stage of their culvert asset management efforts. This chapter summarizes the important aspects of inventory and inspection procedures presented in the ODOT Culvert Management Manual.

CHAPTER 5.0

CULVERT MAINTENANCE, REPAIR, RENEWAL AND REPLACEMENT

5.1 Introduction

The inventory and inspection procedures help agencies record and monitor the culverts they are responsible for operating and maintaining. The appropriate actions to be taken regarding the management of culverts can be classified under the categories of maintenance, repair, renewal and replacement. Maintenance activities are important in terms of avoiding costly emergency repairs, renewals or replacements. Repair procedures involve activities that offer remedies to local problems; therefore these procedures usually do not extend the service life of the whole structure. Renewal and replacement procedures are used to form new pipes instead of the existing ones; therefore these procedures provide new design lives to the structures. The difference between renewal and replacement is that the renewal procedures form the new pipe within the existing one whereas replacement procedures involve complete elimination of the existing culvert either by open-cut method or trenchless methods. The details of maintenance, repair, renewal and replacement methods are going to be discussed in the following sections:

5.2 Culvert Maintenance

Culvert maintenance is one of the key elements of having a working highway drainage system. Timely maintenance activities reduce the risk of having future problems related to the structural, hydraulic and durability aspects. The objectives of the culvert maintenance activities include inspecting the culverts for current performance, removing debris, sedimentation and dirt from the culverts and identifying the probable problems, which might occur in the future. According to FHWA Culvert Repair Manual, culvert maintenance activities can be divided into three categories (FHWA, 1995), as follows:

Routine Maintenance: Routine maintenance activities are performed according to a schedule, which has been determined before. All parts of the drainage structure must be inspected and attention must be paid to all parts equally.

Preventive Maintenance: Preventive maintenance is performed to solve a problem before it causes problems that are more serious in the future. It resembles the routine maintenance with respect to the activities performed but it is not performed according to an already established schedule.

Emergency Maintenance: Emergency maintenance is performed in case of an unforeseen event, which may cause disturbance in the performance of a culvert.

Emergency maintenance can be eliminated if timely routine maintenance and preventive maintenance activities are performed.

According to NCHRP Synthesis Report 303, *Assessment and Renewal of Existing Culverts*, routine maintenance consists of activities to repair specific problems as they occur (NCHRP, 2002). Routine maintenance helps to keep a culvert in a safe working condition. The preventive maintenance is described as a more broad strategy compared to the routine maintenance. The aim of preventive maintenance includes eliminating small progressive deteriorations.

Ohio Department of Transportation's Culvert Management Manual provides a list of probable maintenance and repair activities for the inspectors to use while filling the CR-86 Culvert Inspection Form. The inspector needs to select the appropriate maintenance and repair methods most applicable to culvert under inspection. This list includes the following maintenance activities: Cleaning and reshaping ditches, cleaning channels, cleaning drainage structure, under drain maintenance, cleaning channels removing debris, seeding and fertilizing, and litter pickup.

Cleaning the culvert, channel and ditches from debris, sediment and litter is especially important in order to avoid hydraulic inefficiencies during heavy storms and floods. Debris and sediment may be present due to the differences in seasonal water levels and transportation of solid particles within the water flow. Manpower or machines may be utilized in order to accomplish the debris, sediment and litter removal. If the circumstances prohibit using workers or machines flushing with high velocity water may be employed unless there is a risk of damaging the culvert.

Seeding and fertilizing activities can be thought as planting the surrounding soils of a culvert. The benefits of planting the surrounding soil include preventing erosion of the soil adjacent to the culvert and providing aesthetics. Preventing erosion may be especially important due to the structural integrity of soil culvert interaction.

Another important maintenance activity involves thawing the frozen culverts where sudden temperature drops in cold winter seasons cause ice formation. Steam generators, solar energy collectors or other forms of heat providing measures may be employed to thaw frozen culverts.

5.3 Culvert Repair

If the routine maintenance activities are not enough to solve a problem in a culvert and replacement is not a feasible option then, some of the repair techniques should be employed. Repair activities involve procedures that are more advanced therefore they may require more labor and equipment compared to the routine maintenance activities. Some of the repairing methods for concrete and corrugated metal culverts are going to be covered in this section: (Details of the repair procedures can be found in Appendix 8)

5.3.1 Concrete Culverts

Most common problems associated with concrete culverts are cracks, spalling, invert deterioration, joint defects and misalignment (in precast concrete culverts), and footing problems (in arch type cast-in-place culverts). Federal Highway Administration's Culvert Repair Practices Manual provides a detailed description for each of these problems and it is summarized in the following paragraphs (FHWA, 1995).

Structural loading may cause cracks on precast concrete culverts. Cast-in-place culverts are constructed as a one unit without unconnected joints, which makes these culverts vulnerable for cracking due to their length and rigidity. The repair procedures for cracks involve sealing and patching.

Spalling may be defined as the cracking and detaching of the concrete because of corrosion of the reinforcing bars. As reinforcing bars corrode, they tend to expand and apply pressure on the concrete surrounding them. Detached concrete parts should be replaced by patching as a proper method of repair.

Concrete culverts usually exhibit high resistance to corrosive environments however invert deteriorations are also common types of problems faced with the concrete culverts. Precast concrete culverts are expected to have a higher resistance compared to cast-in-place concrete culverts due to the controlled production environment and lower porosity. The deteriorated parts of the inverts should be repaired by paving the invert or application of proper coating materials such as vitrified clay tiles. If abrasion is an important factor causing the deterioration of the invert, installing a neutralization basin would be a proper method of repair.

Infiltration and exfiltration through cracks at joints can be an important problem for precast concrete culverts. Foundation problems and scouring may lead to differential settlement of precast sections, which may eventually cause cracks and openings at the joints. Application of structural adhesives, chemical grouting and sealing are appropriate methods of repair for cracked joints. Open joints may be sealed with similar methods unless the opening is wide. Wide openings can be repaired by installing steel bands and covering with shotcrete.

Another important problem, which may be experienced with precast concrete culverts, is the misalignment. Uneven settlement of the surrounding soil, improper installation techniques and undermining might be some of the reasons of misalignment. If misalignment is detected excavating and relaying the culvert would be an appropriate solution.

There might be footing problems on arch type cast-in-place concrete culverts with independent footings. The reasons of these problems might be scour and undermining of the footing. The repair solution for this type of problem is underpinning of the foundation. Underpinning is done by excavating beneath the existing footing and constructing another footing underneath.

5.3.2 Corrugated Metal Culverts

Corrugated metal culverts are considered as flexible culverts. Their structural performance depends on the interaction between the structure and the soil envelope surrounding them. Therefore, apart from corrosion and abrasion, backfill gradation and compaction is also important in metal culverts' performance.

Joint defects in corrugated metal pipes, invert deterioration of corrugated metal pipe and structural metal pipes, shape distortions, and distorted and cracked seams in structural plates are some of the most common problems associated with corrugated metal culverts. Federal Highway Administration's Culvert Repair Practices Manual provides a detailed description for each of these problems and it is summarized in the following paragraphs (FHWA, 1995):

Joint defects may cause important problems due to infiltration and exfiltration of water and soil through or from the culvert. This situation may cause loss of support and disturb the soil-pipe interaction necessary for the survival of the pipe. In order to repair joint defects in metal pipes and pipe-arches, excavation and exterior repair, grouting or installation of interior seals methods might be used.

Corrosive and abrasive environmental conditions may adversely affect the invert durability of corrugated metal pipes and corrugated structural plates. Progression of invert deterioration may cause loss of structural integrity of the culvert and may cause the culvert to fail. In order to repair deteriorated inverts of metal culverts, invert paving with concrete, steel armor plating or converting a pipe-arch culvert into an arch type culvert method might be used.

Metal culverts may have shape distortions due to unsymmetrical loading. This loading might be a result of poor installation or might be a result of poor design. If the rate of shape distortion is not progressing with time then there is no need of a corrective action. If shape distortion is progressing with time then temporary bracing, excavation and backfilling, and reshaping might be used as a repair method. According to ORITE study (Mitchell et al, 2005), timber bracing should span the critical points but point loads should be avoided on weak points.

Corrugated metal structural plate culverts have longitudinal seams throughout the structure. There might be distortion and cracks on the seams due to unsymmetrical forces and faulty assembling. Reversing lap joints, welding reinforcing bars, shotcreting beams, excavating, and repairing might be possible solutions to deal with the seam problems.

Corrugated metal arch culverts usually have the natural streambed instead of a bottom part. The arch structure is connected to the concrete foundation below the flow line. Undermining of corrugated metal arch culverts foundations may lead to settlement, rotation, distortion and failures. In order to repair undermining due to scouring underpinning of foundations should be applied.

As previously stated, corrugated metal arch culverts usually have the original soil as the streambed. If there is an excess amount of debris and sedimentation they should be cleaned out with proper equipment. If there is scouring and lowering of the streambed then the streambed material should be changed with an appropriate material.

Figure 5.1 summarizes the common problems and repair methods for corrugated metal culverts and concrete culverts.

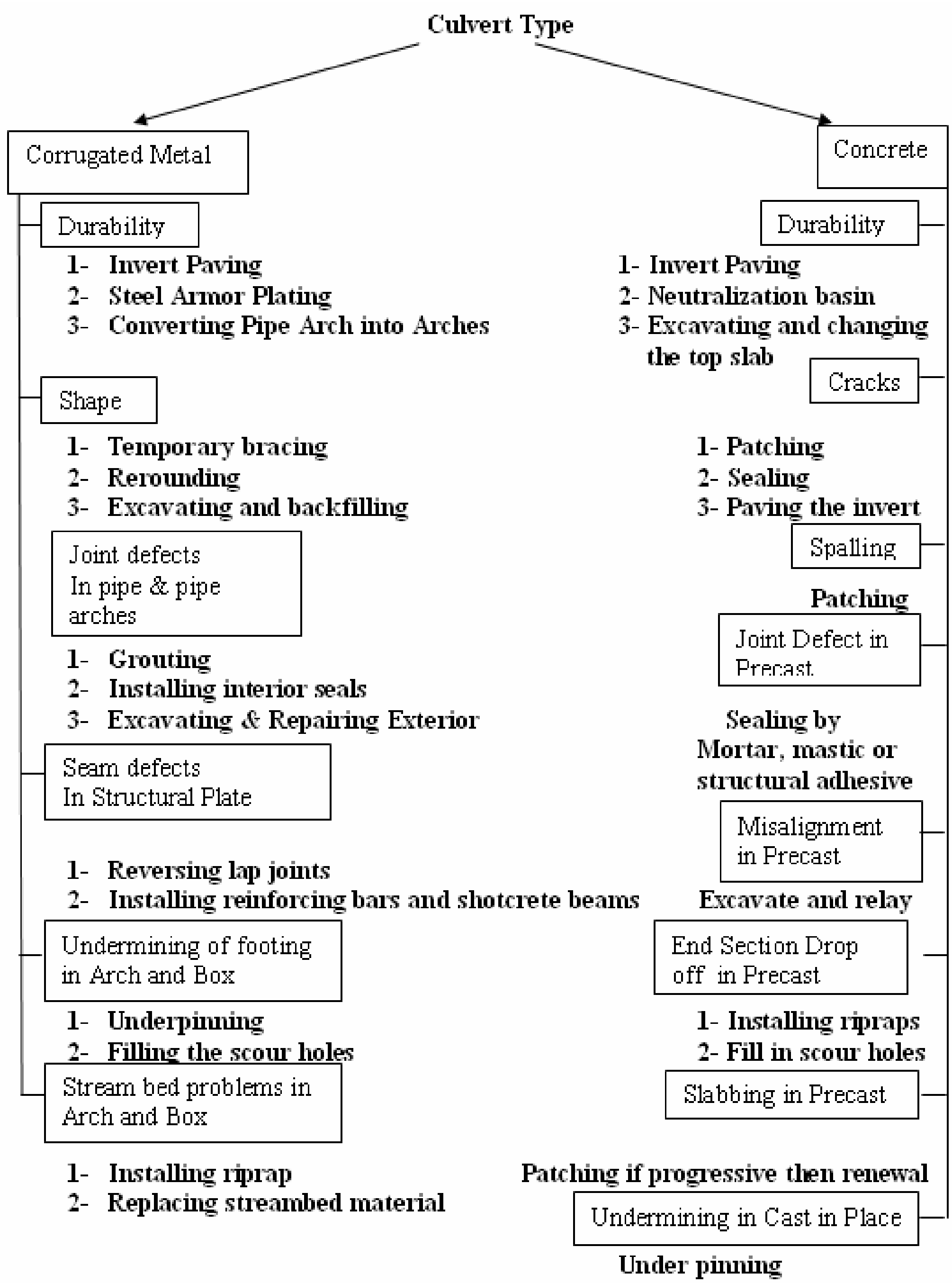


Figure 5.1: Repair Procedures for Concrete and Corrugated Metal Culverts.

5.4 Culvert Renewal and Replacement

When the application of a repair method is not sufficient to bring a culvert back to satisfactory working conditions the culvert must be rehabilitated. FHWA Culvert Repair Manual states that, "When the extent or type of distress severely limits the structural strength or the functional adequacy of an existing culvert barrel and it cannot be effectively repaired, other procedures should be considered to restore the structural strength and the serviceability of the culvert."(FHWA, 1995) Therefore, renewal procedures are usually more costly and technically more challenging than repair methods.

5.4.1 Culvert Renewal

In this report, renewal methods of culverts are going to be defined as renewal methods in which the partially or fully deteriorated pipe is used as the host pipe and a new pipe is formed within this host pipe. Some of the most commonly used renewal methods are, sliplining, cured in place pipe, cement mortar lining, spirally wound pipe and close-fit pipe.

5.4.1.1 Sliplining

Sliplining is the process of inserting a new pipeline into an existing culvert and grouting the annular space. The new pipeline should be selected as a different material, which is more resistant to environmental factors in order to eliminate the previously faced problems. Although sliplining decreases the total cross sectional area of a culvert, using a smoother pipe material with a smaller Manning's Roughness coefficient may eliminate this problem. In order to have a successful sliplining, the existing culvert must be inspected for any bends or irregularities, which may obstruct the pulling or pushing of the new pipe. Once the inspections are completed, the host pipe should be cleaned and prepared for sliplining. The new pipe segments should be joined together, inserted into the existing pipe and positioned. Final step is to grout the annular space between the new lining pipe and the old culvert. Grouting must be completed in phases in order to prevent the new lining material from floating and to have good bonding between the new lining material and the old culvert. Minnesota Department of Transportation made a study (Johnson and Zollars, 1992) about sliplining deteriorated culverts with a variety of materials in order to compare their constructability and costs with open-cut methods. The findings of this study are:

- Smooth Polyethylene pipes had debonding problems due to differences in coefficients of thermal expansion and due to the completion of grouting process in only one step (which caused floating of the liner)
- Spiral Ribbed Polyvinyl Chloride had an inexpensive material cost but pushing ribbed liner through the culvert was difficult. PVC exhibited brittle behavior in cold weather.

- Fiberglass liners had high material costs. Even though the installation was smooth, pushing through corrugated metal exhibited problems. Fiberglass liners are quite heavy, which makes it difficult to handle, compared to other liners.
- Installation of a Spiral Ribbed Coated Steel Arch was the most difficult and time consuming. Ribs on the liner were caught on the rivets and corrugation on the older culvert. Although it was the hardest to install, spiral ribbed coated steel arch provided the least capacity loss.

A very detailed hydraulic analysis has to be performed in order to select the best liner material. Cross sectional decrease has to be compensated with the use of a smooth liner. While making the new culvert smoother, attention should be paid to the new flow velocity, in order to eliminate outlet scouring and in order to allow fish passage from the culvert. Sliplining can be performed without any specialized equipment for structural or nonstructural purposes.

Advantages of sliplining include (Najafi, 2005):

- Expensive specialized equipment is not needed.
- It is a simple technique.
- It can be used for both structural and nonstructural purposes.
- Existing flow does not restrict the process.

Some of the limitations of sliplining are (Najafi, 2005):

- Reduction in the pipe diameter.
- Grouting is required.

5.4.1.2 Cured In Place Pipe (CIPP)

CIPP is a process by which a deteriorated culvert is lined with a continuous lining composed of a liquid thermosetting resin-saturated material. The lining is cured in the installation by heat and thus a cured in place pipe is obtained. In order to use CIPP as a renewal method the existing pipe should be inspected and cleaned. According to the inspections, a flexible tube should be ordered which will serve the unique project requirements. Once the tube is brought to the job site it should be installed using the inversion method or by using a winch. As a final step, the installed tube should be cured by using hot water, steam or UV light.

The advantage of this type of lining is to have a lining without joints thereby eliminating the future joint defects and having a corrosion and abrasion resistant invert. The shape of the structure to be lined with a CIPP does not have to have a circular shape and CIPP can be used in the pipes with bends. However, the existing flow should be bypassed and the cost can be high due to specially produced tube and carefully monitored curing process.

This method was tested in the Minnesota Department of Transportation’s study (Johnson and Zollars, 1992). According to the test results, new liner was conforming closely in shape and very little hydraulic capacity was lost. A specialized crew and equipment was needed in order to perform the lining process. This method was comparable to the conventional open-cut method in terms of price. Therefore, it is justifiable to use this method in urban areas where space and disruption is critical and at locations where significant reduction in hydraulic capacity is not desirable. Pennsylvania Department of Transportation (Sukley and John, 1994) performed another example of inversion lining. The culvert relined was a 48-year-old, asphalt and corrugated metal pipe, which was located in an area close to railroad tracks. Results obtained were satisfactory and despite of its high initial cost, the DOT was able to save $170,000 by using this technique. Najafi et al (2008) reported another study in Roger's Creek below I-196 near South Haven, Michigan, where a twin 80-in. diameter culvert was recently lined with CIPP. The authors found that the CIPP actually improved hydraulic capacity of the culvert in spite of the reduction in cross sectional area.

Advantages of CIPP include (Najafi, 2005):

- Grouting is not necessary.
- Smooth interior surface enabling an increase in flow capacity.
- Lining noncircular shapes is possible.
- Lining can be accomplished even in the presence of bends.

Limitations of CIPP include (Najafi, 2005):

- The tube is custom made for each project.
- Existing flow must be diverted.
- Successful installation depends highly on the curing process.
- It can be expensive.

5.4.1.3 Cement Mortar Lining

Cement mortar lining is used to prevent culverts (especially iron pipes) against corrosion. It is applied by either using a rotating machine or by using shotcrete. The rotating machine helps to fix the mortar to the face of the culvert by centrifugal force. The cement mortar lining is very thin, therefore; it does not contribute to significant hydraulic loss. If reinforcing bars or a steel mash is placed before the application of mortar lining it can contribute to the structural strength of the culvert. The disadvantage of this method is the limited durability of the cementitious coating.

5.4.1.4 Spiral Wound Pipe

In this method of culvert renewal, a new lining pipe is obtained by spirally winding a polyvinyl chloride strip by using a special winding machine on the job site. The continuous spiral lining is watertight and fits very closely to the existing structure, the annular space left between the new liner, and the existing culvert should be grouted. The disadvantage of this type of renewal is dependency on the special winding machine and skilled personnel to use it.

Advantages of spiral wound pipe include (Najafi, 2005):

- Large bends can be accommodated.
- Pipes are not stored on the job site
- Mobilization costs are low.

Limitations of spiral wound pipe include (Najafi, 2005):

- Skillful personnel are needed.
- Annular space should be grouted.

5.4.1.5 Close-Fit Pipe

Close-fit pipes are generated by modifying the cross sectional area of polyethylene pipes, inserting them to the host pipe and returning the cross sectional area to the normal by applying pressure. Modifying of the cross sectional area is accomplished by using a machine to mechanically fold the pipe into a heart shape and holding the pipe in this shape by temporary restraining bands. In this type of renewal, the pipe is manufactured before being brought to the job site, which increases the quality of the finished product.

Advantages of close fit pipe are (Najafi, 2005):

- The new pipe is produced at a controlled environment
- Minimal reduction in the existing pipe area
- Mechanically folded pipes can accommodate 45 degree bends

Limitations of close fit pipe are (Najafi, 2005):

- The diameter and installation range is limited
- A large working space is needed
- Usually the flow needs to be bypassed

5.4.1.6 Panel Lining

Panel lining is a procedure that may be used to renew large diameter noncircular drainage structures. They can be designed either as a self-supporting pipe or as a pipe, which depends on the strength of the existing pipe and the concrete fill in the annular space. In this type of renewal workers enter the pipe and install the panels manually.

Advantages of panel lining (Najafi, 2005):

- Panel lining can be used in any shape of pipe.
- Chemical and abrasive resistant liners can be installed.
- It can be installed under restricted flow conditions.

Limitations of panel lining are (Najafi, 2005):

- Only worker entry pipes can be renewed by this method.
- Grouting must be applied to the annular space.

- Reductions in the cross sectional area may be significant.

5.4.1.7 Thermoformed Pipe

In this type of renewal, polyvinyl chloride or polyethylene pipes are thermoformed inside the host pipes to provide a tightly fitting chemical and abrasion resistant pipe. In order to insert the new pipes they are either “deformed and reformed”, “fused and expended” or “fold and formed”. After insertion, the new pipe is heated and pressurized according to the manufacturer’s specifications. In order to assure the tight fitting the pipe needs to be cooled first and then depressurized.

Advantages of thermoformed pipe are (Najafi, 2005):

- The new pipe is produced at a controlled environment (factory) therefore quality is higher and installation is fast.
- The cross sectional reduction is minimal.
- It can provide a design life of a new pipe.

Limitations of thermoformed pipe are (Najafi, 2005):

- Diameter range is limited.
- Bypassing the existing flow is required in many cases.
- Large working space may be required for some type of installations.

5.4.2 Culvert Replacement

If the current condition of the culvert does not allow forming a new pipe within or if the hydraulic capacity of the culvert is not adequate, replacing the culvert would be the appropriate action. According to NCHRP 303 (2), “If a pipe deteriorates to a point where (1) its structural integrity or soil support is lost; (2) insurmountable problems, such as scour or erosion of the streambed or soil mitigating through pipe joints, are occurring; or (3) the roadway over the pipe is lost, then pipe replacement would be the appropriate corrective action. There are two main types of culvert replacement techniques. First, one is the open cut replacement and the second one is the trenchless replacement.

5.4.2.1 Open-Cut Replacement

Open cut replacement is performed by opening a trench, replacing the old culvert and filling the trench. This type of culvert replacement is the most commonly used method. The disadvantage of this type of construction is to close the road or at least some of the lanes during the construction. This situation not only increases the user costs it may also cause safety problems. Whenever there is a trench construction either a detour or a temporary bypass has to be designed or the construction has to be staged.

5.4.2.2 Trenchless Replacement Methods

The problems related to open cut replacement can be eliminated by using trenchless techniques. Trenchless methods provide safer working environment for workers and avoid the disruption of the traffic. The disadvantage of trenchless methods might be their high initial cost and they may not be suitable for every site due to the space requirements and/or surrounding terrain. Pipe bursting and pipe removal are the two trenchless replacement alternatives for a culvert (Najafi, 2005).

5.4.2.2.1 Pipe Bursting

Pipe bursting involves inserting and pushing a bursting head to the existing pipe, and thereby fracturing the pipe and pushing its parts into the surrounding soil. A new pipe equal or greater in diameter is pushed or pulled immediately behind the bursting head. Most pipe materials can be replaced by using this method.

5.4.2.2.2 Pipe Removal

Unlike pipe bursting, in this method the existing pipe is not pushed into the surrounding soil rather it is removed from the ground after being pulverized. This method resembles a new trenchless construction of a pipe.

5.5 Chapter Summary

This chapter described the maintenance, repair, renewal and replacement options commonly employed while managing culverts. Performing timely maintenance procedures significantly reduces costly emergency repairs. Concrete culverts and metal culverts are examined in terms of common problems and repair methods which can be used to eliminate these problems. A flowchart is developed to summarize the repair options for various problems. Culvert renewal methods which are used to extend the service life of culvert without replacement are explained. Open-cut replacement and trenchless replacement methods are also covered.

CHAPTER 6.0

DEVELOPING A CULVERT ASSET MANAGEMENT PROTOCOL

6.1 Introduction

Asset management of a roadway infrastructure element essentially involves performing periodic inspections of the asset and making proper decisions regarding whether to employ any corrective actions according to the asset's current and future expected performance. Based upon the inventory and inspection procedures of ODOT Manual, this chapter presents a culvert asset management protocol. The application of this protocol will enable transportation agencies to follow a systematic way in terms of tackling problems and will help them choose the proper methods given the conditions of the culvert. The proposed protocol provides guidelines for establishing an inventory and inspection database, performing culvert inspection and routine maintenance and deciding on repairing or renewing the culvert.

6.2 Establishing Inventory and Inspection Database

The first step of implementing a successful culvert asset management strategy is to establish a database consisting of an inventory of existing culverts and to establish a systematic inspection procedure. The inventory information should include all the items related to the location of the culvert, geometry and structural properties of the culvert and extensions, and hydrological / hydraulic properties of the culvert. The inventory information for a culvert should be added to the database whenever a new culvert is constructed and it should be modified whenever changes to an existing culvert have taken place.

The systematic culvert inspection procedure should include items related to the conditions of culvert barrel, shape and alignment, the condition of joints or seams, the condition of channel protection, the condition of pavement located above the culvert and the condition of the embankment. The items in the culvert inspection procedure can be modified according to the environmental conditions of the culvert location. Essentially, the inspection procedure should include all the components of a culvert and a detailed rating system for each of these items should be developed.

The ODOT Culvert Management Manual provides both inventory and inspection forms and describes each of them with very detailed explanations. Therefore, the manual provides a great starting point for those agencies who want to establish an inventory and inspection database. In order to make full use of these databases they should be designed to be compatible with each other and the inventory and inspection procedures should be standardized through the whole agency thereby leaving no blank fields for any item on the inventory or inspection form.

6.3 Performing Culvert Inspection and Culvert Maintenance

Culverts should be inspected at a regular basis to monitor their conditions and to take timely and economical precautions. The ODOT manual proposes to inspect culverts with a 5-year frequency (ODOT, 2003). The time interval between consecutive inspections of culverts with known problems should be lower than newly constructed ones. Maintenance activities are important to reduce more costly and time-consuming emergency repair and renewal operations. Therefore performing routine maintenance activities such as debris, sediment and litter removal along with periodic inspections would be very beneficial.

6.4 Decision on Repairing or Renewing

If the routine maintenance activities do not provide a solution to the problems associated with a deteriorated culvert then a decision needs to be made whether to repair, renewal or replacement the culvert needs to be considered. In this section, a decision platform is introduced in order to provide a solution to this problem. According to ODOT Culvert Management Manual, the inspector is asked to fill in the general condition of the culvert on the inspection sheet. The inspector selects one of the codes according to Table 6.1.

Table 6.1: General Appraisal Codes (ODOT, 2003)

Code	Description
9	As built condition
8	Very good condition - no problems noted
7	Good condition - some minor problems
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

It is possible to divide the culverts into 4 risk zones by using Table 6.2.

Table 6.2: Risk Zones for Culverts

General Appraisal	Risk Zone
9, 8	Routine maintenance sufficient, no repair required
7, 6	Culvert needs repair
5	Culvert needs several repairs or renewal
4, 3, 2, 1, 0	Culvert needs to be renewed or replaced

6.4.1 First Risk Zone

The culverts with a general appraisal rate of 9 and 8 do not need any repair activities due to their excellent condition. Routine maintenance activities are enough to solve any encountered problems.

6.4.2 Second Risk Zone

The culverts, which fall into second risk zone, suffer from minor problems. In order to solve these problems, the repair methods addressed in culvert repair section can be employed. Do-nothing option can be evaluated against the repair procedures by using a benefit/cost analysis.

6.4.3 Third Risk Zone

The culverts, which fall into third risk zone, are in a condition ranging from satisfactory to poor condition. This zone can be thought of a transition stage between satisfactory and critical stages. Several different defects may occur at the same time, and repairing each one of them may not prove to be efficient, therefore in some cases using trenchless renewal methods may provide solutions that are more efficient. Using a life cycle cost analysis and comparing the net present value of repair costs by incorporating any additional future costs with a major trenchless renewal cost should be performed. Future plans about the culvert site should be examined. If any major land use change in the proximity is predicted then lining the culvert with a smoother material would be an appropriate solution or if any major renewal project involving the roadway over the culvert is foreseen, repairing the culvert with the least possible initial cost and avoiding a costly renewal is the right procedure to follow. The steps to be followed are as follows:

Step 1: Examine the inspection sheet and determine the problem areas.
Step 2: Generate alternative solutions (repair and trenchless renewal methods) to tackle these problem areas.
Step 3: Determine the agency’s own force requirements for each alternative
Step 4: Determine the availability of contractors for each alternative
Step 5: Determine funding availability
Step 6: Determine the plans for the surrounding area and the roadway.

Step 7: Eliminate the alternatives generated in step 2 by using the criteria generated in steps 3 through 6.
Step 8: Determine the service life and future maintenance costs of each remaining alternatives.
Step 9: Choose the alternative with the least life cycle cost analysis.

6.4.4 Fourth Zone

The culverts, which fall into the fourth risk zone, need immediate action either by replacing or a major renewal action. Open cut replacement is the most common method of replacing culverts however if the location is an interstate or the annual daily traffic is high, using a trenchless renewal technique would be more appropriate due to high user costs and safety concerns. Hydraulic capacity of the culvert is another important aspect of culvert renewal. While renewing a culvert, future trends in the capacity requirements of the drainage area should not be ignored. The steps to be followed are similar to zone 2 except that the decision is now whether to use trenchless methods to renew (rehabilitate or replace) the culvert or to do an open cut replacement.
Figure 6.1 and Table 6.3 summarizes the decision-making procedure for culvert repair, renewal and replacement.

6.5 Validation of the Decision Platform

The Ohio Department of Transportation has validated the Culvert Asset Management Decision Platform. Before reaching the final version of the platform, which is presented here, there have been several discussions and revisions in order to reach a final version of the platform.

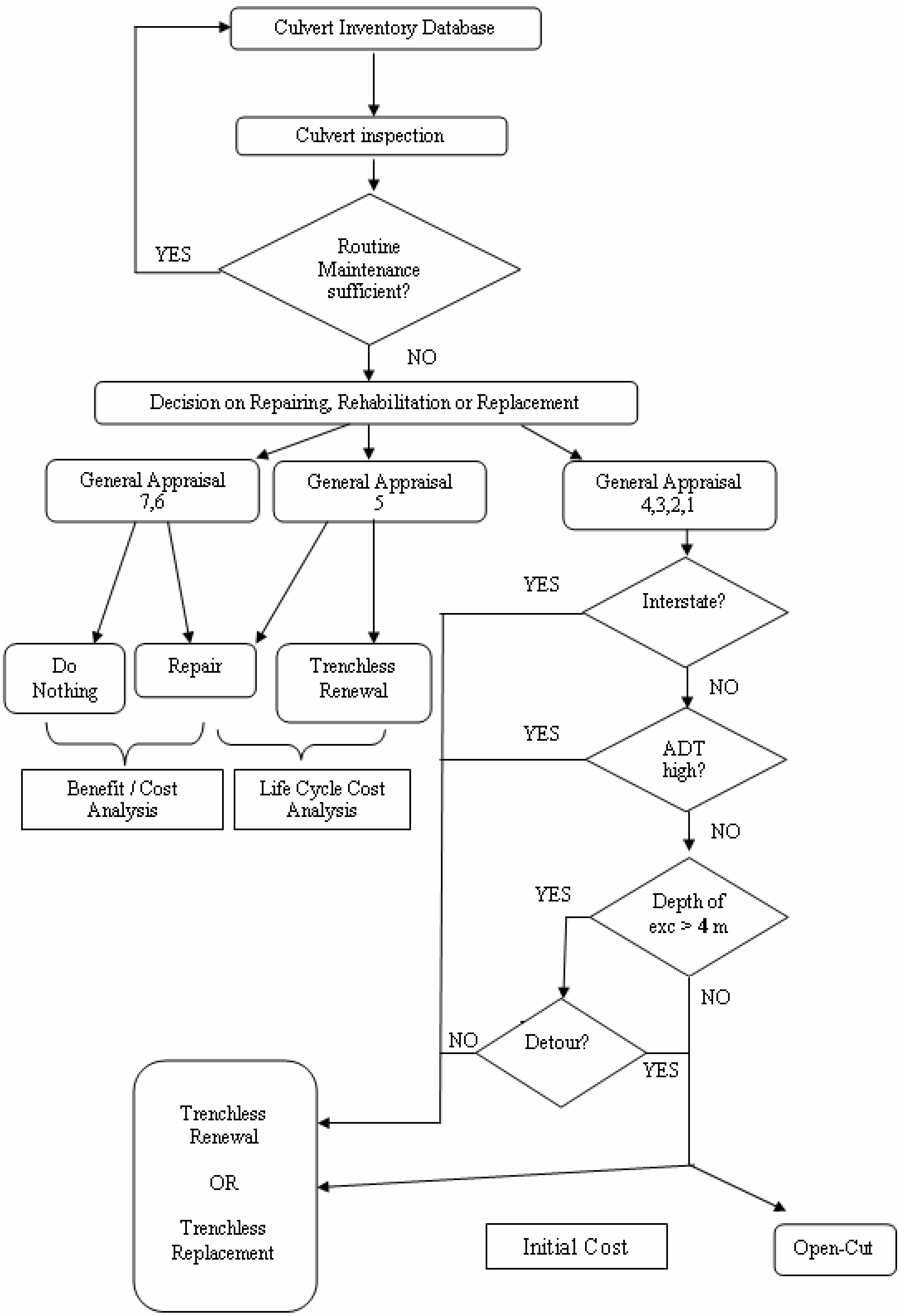


Figure 6.1: Culvert Asset Management Decision Platform.

Table 6.3: Culvert Repair, Renewal and Replacement Methods.

Repair Procedures:	***Trenchless Renewal***	***Trenchless Replacement***
Durability: Invert Paving Steel Armor Plating Neutralization basin Shape: Rerounding Temporary bracing Cracks: Patching Sealing Paving the invert Joint Defects: Grouting Sealing Seam Defects: Reversing lap joints Reinforcing and Shotcrete Undermining: Underpinning	- Sliplining - CIPP - Cement Mortar Lining - Spiral Wound Pipe - Close Fit Pipe -Panel Lining -Thermoformed Pipe	- Pipe Bursting - Pipe Removing

6.6 Chapter Summary

Asset management of a roadway infrastructure element essentially involves performing periodic inspections of the asset and making proper decisions regarding whether to employ any corrective actions according to the asset's current and future expected performance. Therefore, this chapter presented a culvert asset management protocol based upon the inventory and inspection procedures of ODOT Manual. The culvert asset management protocol presented here will enable transportation agencies to follow a systematic way in terms of tackling culvert asset management problems. The suggested guidelines can be used to establish an inventory and inspection database, perform culvert inspection and routine maintenance and decide on repairing or renewing the culvert.

CHAPTER 7.0

CULVERT INVENTORY MODEL

7.1 Introduction

An inventory model is an important component of a good asset management framework. It helps the state DOTs and local governments to measure the current level of service, conditions of their assets, and their customers' expected level of service. Through this model, agencies can manage the asset infrastructure to the level of service expected by the customers' and determine the future investment to maintain these assets. The most important aspect of asset management is the knowledge of ownership. Planning for asset renewal or renewal is not possible until these agencies know exactly what assets they own, and where these assets are located. Developing a good asset inventory model is a prerequisite to asset management planning.

7.2 Benefits of an Asset Inventory Model

The benefits of developing an asset inventory model in preserving the infrastructure assets are as follows (FHWA, 2005):

- With an asset management inventory model, it is easy to locate all types of assets using an uniform location reference system.
- Asset data can be shared across departments, divisions, sections, and units in various geographical locations. Sharing information effectively would develop a transparent culture in the organization, which fosters cooperative approaches to problems and needs.
- It improves analysis, reporting, and display capabilities for effective decision making between decision makers, policy makers, and the public.
- An inventory model eliminates inconsistencies and conflicts among databases.
- It improves data collection methods, which can save money and internal data consistency.
- It develops uniform measurement units and measurement methods throughout the state, improving the reliability of asset attribute measurement.
- It develops a broad, integrated approach for asset management programs

7.3 Culvert Inventory Model

The culvert inventory model is a process of identifying and numbering the culverts in a systematic and defined way. It provides a starting point for greater understanding and identification of culverts, which were overlooked for years. This model is a set of useful questions in the form of a protocol used to identify the culverts. The identification includes logical details of the culvert, its components, and the surrounding area. Once these culverts are identified and entered in the inventory database using the unique identification number, they can be linked to various information and decision support systems for financial, economical, and management purpose. The model consists of fifty-five questions grouped in six modules – general, structural, hydraulic, safety, repair and additional information. All the questions will be coded as presented in the inventory manual (Appendix 2). There are two types of coding:

- National Standards like the Federal Information Processing System (FIPS).
- User defined.

The information and coding when incorporated into the system database must exhibit the following characteristics (Pantelias, 2005).

- Integrity: whenever two data elements represent the same piece of information, they should be equal.
- Accuracy: the data values represent as closely as possible the considered piece of information.
- Validity: the given data values are correct in terms of their possible and potential range of values.

The general identification of the culvert location is the first module in the inventory model. This module aims in identifying the culvert from bigger region to specific culvert structure.

The items covered in this module are:

- *State code*: coding of the culvert based on state codes. It follows the Federal Information Processing System (FIPS) standards.
- *County Code*: coding of the culvert based on the state counties. It follows the FIPS standards.
- *Place Code*: coding of the culvert based on the cities, townships and villages. It follows the FIPS standards.
- *Inventory Code*: it is a unique identification number for culverts based on route signing, level of service, route number, direction and the structure number.
- *Mile Marker*: coding of the culvert based on the nearest mile marker on the roadway.
- *Year Built*: year in which the culvert was built. This can be determined through as built drawings.
- *Latitude and Longitude*: latitude and longitude coordinates of the culvert can be determined using the Global Positioning System (GPS) techniques.
- *Maintenance Responsibility*: the primary responsibility of the agencies in maintaining the culverts will be coded.
- *Average Daily Traffic (ADT)*: the ADT of the route under which culvert exists.
- *Approach Roadway Width*: is the width of the roadway above the culvert.
- *Culvert marker*: the type of culvert marker used is coded.

The second module in the inventory model is the structural information. This module is very important to understand the structural concepts or design of the culvert. It can be used as a benchmark to measure the structural deteriorations during inspection.

The identification items in this module are:

- *Culvert Shape.*
- *Material.*
- *Number of Cells.*
- *Length.*
- *Diameter.*
- *Span.*
- *Rise.*
- *Other Geometric Dimensions.*
- *Pitch, Depth, and Gauge* (for CMP only).
- *Height of the cover from crown of the culvert to road surface.*

The third module in the culvert inventory model is the additional information, which identifies the components of the culvert and other features. This module acts as a benchmark for various culvert component distress or deficiencies.

The identification items in this module are:

- *End Treatment – Type, Material, and Thickness.*
- *Slope of Embankment.*
- *Skew Angle.*
- *Roadway Material.*
- *Number of Lanes.*

The fourth module is the identification related to hydraulics of the culvert. Hydraulic features are the major factors affecting the design performance of the culverts. Identification of these features in the inventory model acts as a benchmark during culvert inspection and determines the rate of deterioration of the culvert due to hydraulic factors.

The items considered in this module are:

- *Type of Stream Bed Material.*
- *Drainage Area Surrounding the Culvert.*
- *Design Peak Flow.*
- *Manning's Coefficient 'n'.*
- *Design Discharge 'Q'.*
- *Design Headwater Depth.*
- *Slope of the Culvert.*
- *Bank Protection.*
- *Type of Fish Passage.*
- *pH of Water.*

The fifth module is the identification of the safety features of the culvert like culvert rails or guardrails. The identification and assessment of these features are a part of highway safety for travelers. In addition, defects in these components indicate problems in the culvert underneath them.

The items in this module are:
- *Type of Safety Component.*
- *Material.*
- *Span.*

The sixth and final module in the culvert inventory model is the identification of previous repair or renewal to the culverts. This information gives an understanding of the problems or defects existed in the culverts and methods or techniques used in repairing or rehabilitating them.

The items in this module are:
- *Type of Renewal and date renewed.*
- *Type of Renewal and date rehabilitated.*

7.4 Chapter Summary

This chapter presented development of a culvert inventory model. The output of the model is a protocol with a set of useful questions. The six modules of the model cover all the necessary details for implementation of an effective asset management framework. While collecting culvert information in the model, inspectors should check the data for its accuracy. The inventory program should enable quality control procedure for data collection such as:

- Using historical data for verification.
- Calibrating all the data collecting equipment.
- Proper storage and management of the collected data.
- Establishing standard procedures for collecting data.

Authors have used ORITE (2005) to derive terminologies and illustrations for the culverts inventory protocol used in Appendix 2.

CHAPTER 8.0

CONDITION ASSESSMENT (INSPECTION) MODEL

8.1 Introduction

Asset management is a continuous improvement process, which includes construction, preservation and disposal of infrastructure assets to optimize service delivery and cost over its entire life cycle. For continuous improvement in the system, we need to have knowledge of the existing assets, their current condition and remaining service life. In 1999, American Society of Civil Engineers (ASCE) conducted a study on wastewater utilities under Environmental Protection Agency (EPA) Cooperative Agreement. Their study reported that an average of 57.5% of the assets was reported to be between 21 and 100 years old, 41.1% reported as between 21 and 50 years old, and 16.8% greater than 51 years old. The data suggested that by 2020, half of the assets would be midpoint of their useful service life. Culverts, which are not inspected and maintained regularly, deteriorate faster than expected due to various changing environmental, hydraulic and social conditions. This will lead to a higher emergency or replacement cost as shown in Figure 8.1 (EPA, 2005).

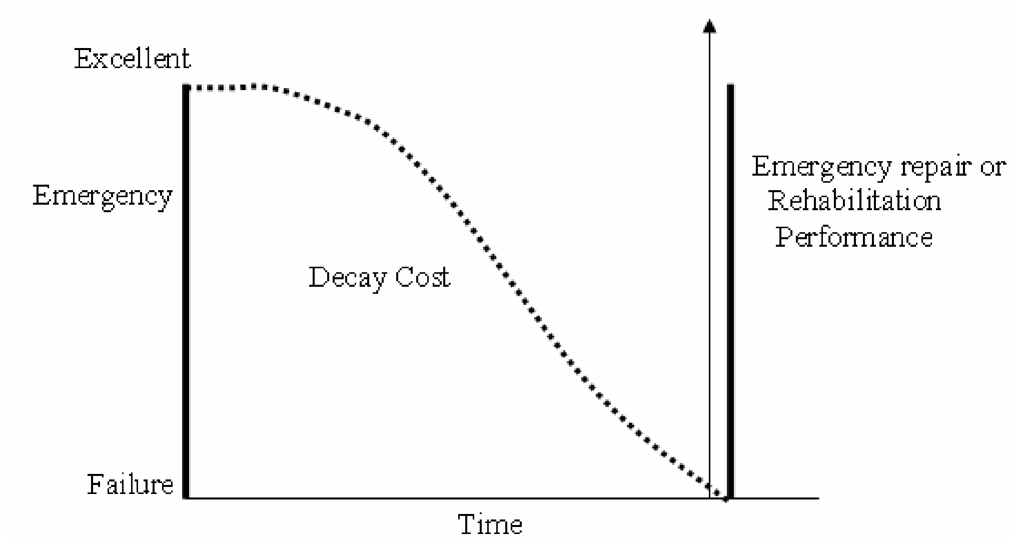


Figure 8.1: Asset Deterioration Curve

The lack of knowledge of the condition of culverts, duration of their use and remaining service life present difficulty in terms of determining which improvements to make and when to make these improvements, in order to ensure their sustainability. General deterioration of the culverts in the past few years has increased the risk of catastrophic breakdown, thus demanding an effective condition assessment model (Lalonde et al, 2003). The benefits of developing a condition assessment model are:

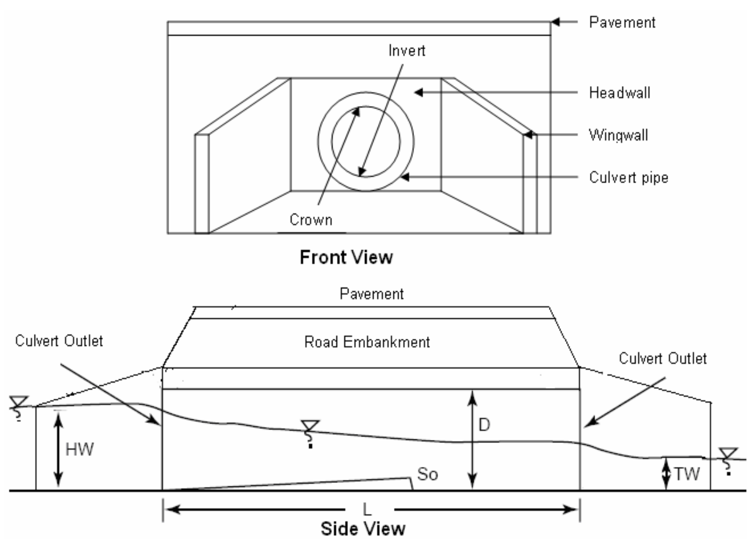
- Through condition assessment model, the culvert utilities can be better understood.

- Risk of sudden failure can be minimized by analyzing the likely failure mechanisms.
- Maintenance and optimization plans can be developed.
- Culvert performance and utilization can be assessed.
- Estimate the remaining service life of the culverts.
- Development of short and long range asset management plans.
- Development of culvert condition rating system.

8.2 Condition Assessment Model

The condition assessment model is a set of protocols that identifies the culverts, which are underperforming, determines the reasons for its deficiency, predicts when failure is likely to occur and develops short and long-term plans for their preservation. This model is based on the inventory model developed in chapter 4, literature review, national survey results, field studies and discussions with the Departments of Transportations (DOTs). Some of the pictures in the inspection manual are derived from (Mitchell et al, 2005). The condition assessment model is divided into two categories:

- *Basic Condition Assessment*, and
- *Advanced Condition Assessment*



D = Diameter of Culvert
S0 = Slope of Culvert
HW = Headwater Depth
TW = Tailwater Depth
L = Length of Culvert

Figure 8.2: Components of a Culvert

8.3 Basic Condition Assessment (BCA)

The basic condition assessment is the general inspection of the culvert, its components and surrounding area. It is the quickest way of collecting relevant and good information during inspection. The assessment begins with recording the general identification of the inspection site and the culvert structure. Then the various components of the culvert are inspected for defects against a condition rating system. The culvert and its components are assigned a condition rating as shown in Table 8.1 and recorded in the protocol. Using AHP, relative weights for these components are assigned and culvert performance score is calculated. Based on the performance score, the culvert is categorized into three zones:

- *Critical Zone (Red Zone)* – The culverts in this zone are in the verge of failure and need immediate attention
- *Monitored Zone (Yellow Zone)* – The culverts in this zone are in intermediate stage. They should be taken care after the culverts in Critical zone are addressed
- *Satisfactory Zone (Green Zone)* – The culverts in this zone are safe and free from deterioration.

The culverts which fall in the danger zone are further investigated for "Advanced Condition Assessment." Based on the zoning, short and long range planning for culvert preservation and maintenance is implemented.

Table 8.1: Condition Rating

Rating	Description
5	Excellent
4	Good
3	Fair
2	Poor
1	Failure/Critical

The condition assessment of a culvert is a complex process, and it involves two main areas:

1. Knowledge or thorough understanding of the culverts and the causes of their deterioration (structural, hydraulic and environmental factors), and
2. Field experience.

To integrate knowledge and experience and make it global, we need a decision support system based on mathematical analysis and human psychology. AHP (Analytical Hierarchy Process) is a decision support system based on piece-wise comparison of the culvert components and deterioration factors. The researchers adopted this method after thoroughly discussing with the MDOT field engineers inputted the matrixes for culvert analysis.

Module One of the basic condition assessments is about general information. The identification of the inspection site is very necessary for any condition assessment system. The items in this module are the same items considered in the module one of the inventory model.

They are as follows:

- *State Code*
- *County Code*
- *Place Code*
- *Culvert Identification Number*
- *Year Built*
- *Date of Inspection*
- *Inspector's Name*
- *Maintenance Responsibility*

Module Two is the culvert site information. Documentation of the site information is necessary because deteriorated site conditions may indicate the deterioration of the culvert and its components. In addition, recording the time, season and temperature during the inspection is important because they have some influence on the effectiveness of the inspection.

The items in this module are:

- *Inspection Season*
- *Climate*
- *Time of Inspection*
- *Type of Stream*
- *Type of Inspection*
- *Water Level*
- *pH of Water*
- *Soil Resistivity*
- *Vegetation*
- *Natural Hazards*

Module Three is the identification of culvert. Basic structural understanding is very necessary before inspection of the culverts. Comparison of the inspected geometric dimensions with the design dimensions would indicate various structural defects.

The items in this module are:

- *Shape*
- *Material*
- *Number of Cells*
- *Type of End Treatment*
- *Geometric Dimensions*

Module Four is the condition assessment of the culvert. GASB 34 requires a measurement or rating scale be used for condition assessment of any asset and a minimum acceptable condition be established as a benchmark. This module lists the various components of the culvert to be inspected against a condition rating system as shown in Table 8.2, which defines the various degree or magnitude of the defects. The inspector should carefully inspect the culvert and assign a single rating for all the components.

The condition rating system for various components of the culvert is as follows:

A. Condition of the Invert

Definition of Invert: The flow line in a channel cross section, pipe, or culvert. The lowest point in the channel cross section or culverts or sewers or the floor, bottom, or lowest part of the internal cross section of a conduit.

Condition of the inverts has a major impact on the performance of the culvert. Common problems with the inverts are abrasion, corrosion and settlement of debris. Age deterioration was seen in most of the culverts during initial field study. Table 8.2 presents the condition rating system for culvert inverts.

Table 8.2: Condition Rating System for Inverts

Rating	Condition
5	Looks new or in excellent condition
4	Age deterioration is minor, no deformations of the openings, no or less settlement of the debris, invert not corroded or eroded
3	Age deterioration is moderate, some deformations of the opening, minor cracks, moderate settlement of debris, inverts corroded or eroded
2	Age deterioration is significant or failure of the inverts is imminent, inverts heavily corroded or eroded, large settlement of debris, major cracks
1	Ends totally/partially broken

B. Condition of End Protection (Headwall, Wingwall)

Definition of End Protection (Headwall, Wingwall): The structural appurtenance usually applied to the end of a culvert inlet and outlet or storm drain outlet to retain an adjacent highway embankment and protect the culvert ends or storm drain outlet and highway embankment or storm drain outfall from bank erosion and channel bed scour.

End protections like headwall and wingwall are usually concrete structures. They should be inspected for common concrete problems like cracks, spalling, scaling, leakage, efflorescence and reinforcing steel corrosion. Table 8.3 gives the condition rating system for end protection.

Table 8.3: Condition Rating System for End protection

Rating	Condition
5	Looks new or in excellent condition
4	Good condition, light scaling, hairline cracking, no leakage, no spalling, minor rotation
3	Horizontal and diagonal cracking with or without efflorescence, minor rusting, leakage and erosion, minor scaling, differential or rotational settlement
2	Cracking with white efflorescence, major cracks, failure is imminent, heavily scaled or rusted, partial collapse of end protection
1	Total/partial collapse of end protection

C. Condition of the Roadway

Definition of Roadway: The portion of the deck surface of a bridge or of an approach embankment, causeway, or cut intended for vehicular and pedestrian traffic.

The condition of the roadway above the culvert indicates the structural or hydraulic problems in the culvert. Settlement of the roadway is the common problem and is due to poorly compacted embankment material. Cracks and pavement patches indicate the structural problems associated with the culvert. Table 8.4 gives the condition rating system for roadway.

Table 8.4: Condition Rating System for Roadway

Rating	Condition
5	Looks new and in excellent condition
4	Minor settlement of the roadway, no cracks
3	Minor settlement of the roadway and minor cracks
2	Heavy settlement of the roadway or major cracks
1	Roadway collapse is imminent

D. Condition of the Embankment

Definition of Embankment: Bank of earth or stone built to carry a road or railroad over an area of low ground.

Deterioration of embankments indicates defects in culvert. Erosion is a common problem, which can be due to undercutting and rotation of culvert footings or severe differential settlement. Embankment defects sometimes lead to cracking in headwall or wingwall. Table 8.5 presents the condition rating system for culvert embankments.

Table 8.5: Condition Rating System for Culvert Embankment

Rating	Condition
5	Soil in very good condition, no erosion found in and around the structure
4	Minor erosion away from the structure, no problem to the culvert
3	Moderate erosion near the structure, no cracks on the headwall
2	Slope stability problem near the culvert, extensive hairline cracks found near the headwall
1	Embankment has collapsed or failure is imminent

E. Condition of the Footings

Definition of Footing: The enlarged, lower portion of a substructure of a culvert that distributes the load to the earth; the most common footing is the concrete slab.

Footings should be inspected for settlement along the length of the footing, which is generally due to erosion. CMP can tolerate some differential settlement but will be damaged due to excessive settlement. The stretching or compression of CMP results in cracking or crushing across the footing. Deterioration in concrete footings may lead to distortions. The condition rating system for culvert footings is as shown in Table 8.6.

Table 8.6: Condition Rating System for Culvert footing

Rating	Condition
5	Footing intact and in good condition
4	Minor erosion or cracking or settlement in the footing
3	Moderate cracking or differential settlement of the footing
2	Severe differential settlement has caused distortions in the culvert
1	Culvert has collapsed or failure is imminent

F. Overall Condition of Culvert

The overall condition of the culvert is determined by taking into account all the hydraulic, structural, environmental and social factors. The analysis is done irrespective of the culvert type and size as per Table 8.7.

Table 8.7: Condition Rating System for Overall Condition of the Culvert

Rating	Condition
5	Newly installed or lined culvert
4	Looks new with possible discoloration of the surface, galvanizing partially worn, hairline cracking, no settlement of the above roadway, light deformation, no debris inside the structure, light corrosion inside or outside the culvert
3	Medium rust or scale, pinholes throughout the pipe material, minor cracking, slight discoloration, isolated damages from cracking, minor settlement of the roadway, minor deformation of the culvert, minor settlement of debris inside the culvert
2	Heavy rust or scale, major cracks with spalling, exposed surface of the reinforcing steel, heavy settlement of the debris inside the structure, visible settlement of the above roadway, heavy deformation
1	Culvert is structurally or hydraulically incapable to function, exceeded its design life, culvert partially collapse or collapse is imminent

Module Five is the calculation of performance score for the culvert. The steps followed in calculating the relative weights for all the components selected above are as follows:

Step 1: Each culvert component selected above is pair wise compared with remaining components in its importance on the overall performance of the culvert. Table 8.8 is used for pair wise comparison.

Table 8.8: Scale for Relative Importance for Pair Wise Comparison

Importance Level	Description
1	Equal Importance
2	Moderate Importance
3	Intermediate Importance
4	Strong Importance
5	Extreme Importance

Step 2: The matrix of comparison is developed after all pair wise comparisons are made as shown in Table 8.9. The values entered in the matrix of comparison are based on the researcher's knowledge in culvert inspection and maintenance.

Table 8.9: Matrix of Comparison for Culvert Performance Calculation

	Culvert	*Invert*	*End Treat*	*Footing*	*Roadway*	*Embankment*
Culvert	1	3	3	3	5	5
Inverts	0.333	1	2	2	4	4
End Treat	0.333	0.5	1	2	2	2
Footing	0.333	0.5	0.5	1	4	2
Roadway	0.2	0.25	0.5	0.25	1	1
Embankment	0.2	0.25	0.5	0.5	1	1
	2.399	5.5	7.5	8.75	17	15

Step 3: The values in the shaded region are the reciprocals of the corresponding elements above the main diagonal. Next step is to normalize the column by summing all the elements in a column and dividing each element in that column by this sum. For the first column, each element will be divided by (1 + 0.333 + 0.333 + 0.333 + 0.2 + 0.2) = 2.399. Thus, new values in the first column are (1/2.399) = 0.4168 , (0.333/2.399) = 0.1388 , (0.333/2.399) = 0.1388 , (0.333/2.399) = 0.1388 , (0.2/2.399) = 0.0834 , (0.2/2.399) = 0.0834 . The normalized matrix is presented in Table 8.10.

Table 8.10: Normalized Matrix for Culvert Performance Calculation

	Culvert	*Invert*	*End Treat*	*Footing*	*Roadway*	*Embankment*
Culverts	0.4168	0.5454	0.4000	0.3428	0.2941	0.3333
Inverts	0.1388	0.1818	0.2666	0.2285	0.2352	0.2666
End Treat	0.1388	0.0909	0.1333	0.2285	0.1176	0.1333
Footing	0.1388	0.0909	0.0666	0.1142	0.2352	0.1333
Roadway	0.0834	0.0454	0.0666	0.0285	0.0588	0.0666
Embankment	0.0834	0.0454	0.0666	0.0571	0.0588	0.0666

Step 4: The final step is to add all elements in a row of the normalized matrix and divide it by the number of elements in that row. Therefore, for the first row, the new value is (0.4168 + 0.5454 + 0.4000 + 0.3428 + 0.2941 + 0.3333) / 6 = 0.3888. Similar calculations are done to obtain relative weights of the remaining rows. The relative weights of the components according to their importance level in performance calculation are as shown in Table 8.11.

Table 8.11: Relative Weights of the Culvert Components

Type	Relative Weights
Overall Culvert Condition	0.3888
Condition of Inverts	0.2196
Condition of End Treat.	0.1404
Condition of Footings	0.1299
Condition of Roadway	0.0583
Condition of Embankment	0.0630

Module Six is the zoning of the culverts based on their performance. The formula for calculating performance score of the culvert is as follows:

$$\text{Performance Score of the culvert} = \sum \text{Condition Rating x Relative Weight}$$

The performance score of a culvert is a factor used as a benchmark to develop short and long term planning. Based on the performance score, the culvert is zoned into three categories – Critical (Red), Monitored (Yellow) and Satisfactory (Green). The maximum score a culvert can obtain is 5.0 and minimum is zero (0). The scoring system is as shown in the Table 8.12.

Table 8.12: Culvert Performance Zones

Performance Score	Zone	Zone Meaning
Above 3.5	Satisfactory (Green)	Safe
3.5 – 2.5	Monitored (Yellow)	Intermediate
Below 2.5	Critical (Red)	Danger

8.4 Advanced Condition Assessment (ACA)

Advanced condition assessment is a detailed inspection of the culvert structure. Any culvert with a performance score below 2.5 is inspected for specific problems, which has caused decay. The objective of ACA is to have a condition rating system for problems causing deterioration specific to concrete, metal and plastic culverts. The assessment begins with the detailed inspection at the inlet, outlet and inside the culvert pipe. The condition rating system between 5-0 is used as a benchmark in identifying the problems. Using AHP, as described in basic condition assessment, relative importance weights are calculated for all the culvert problems as shown in Tables 8.13 and 8.14 (see Appendix 4 for calculations). Tables 8.15, 8.16 and 8.17 show the advanced condition rating for concrete, metal and plastic culverts. Performance score for the culvert is calculated using the following formula:

$$\text{ACA Performance Score of the culvert} = \sum \text{ACA Condition Rating x Relative Weight}$$

Then, the inspector recommends repair or renewal to fix the specific problem causing culvert deterioration. After the culvert is treated, performance score is calculated to check the percent performance improvement in the culvert using the following formula:

$$\text{Percent Performance Improvement} = \frac{(PS)_F - (PS)_I}{(PS)_F} X100$$

Where, $(PS)_F$ = Performance score after the culvert is repaired or rehabilitated

$(PS)_I$ = Performance score when the culvert problem was identified or before

Repair or renewal of the culvert

Table 8.13: ACA Condition Rating Factors and their Relative Weight for Concrete Culverts.

Condition Rating Factors	Relative Weight
Cracking	0.3285
Scouring	0.1478
Settlement	0.1478
Joint Opening	0.1571
Misalignment	0.1571
Concrete Surface	0.0616

Table 8.14: ACA Condition Rating Factors and their Relative Weight for CMP.

Condition Rating Factors	Relative Weight
Misalignment	0.2351
Settlement	0.1378
Vegetation	0.1378
Seam	0.1748
Shape	0.1748
Corrosion	0.1048
Scouring	0.0693

Table 8.15: Advanced Condition Rating for Metal Culverts.

Rating	Corrosion	Abrasion	Seams or Joints	Misalignment and Settlement	Shape	Deposits or Debris	Scouring
5	No Corrosion – galvanizing (or other coating) still intact	No Abrasion – Little roughness to the finished surface of the material.	Tight Joint, No openings at the joints, light surface rust on bolts.	Straight line between sections or minor settlements.	No deflection, Culvert in new condition	No Debris – The flow is not obstructed.	No evidence of scour at either inlet or outlet of culvert or minor scour holes developing at inlet or outlet.
4	Minor Corrosion – minor pitting, tight flakes	Minor Abrasion – loss of finished surface (or Coating)	Minor openings at the joints less than 1/8th inch, minor cracks on both sides of the bolts.	Minor misalignment at joints; offsets less than ½ inches. Minor settlement, Ponding between 3 to 5 inches in depth at joints.	Minor flattening of the walls, or less than 5% change in diameter, (span)	Minor waterway blockages are caused between 0-10% of the total cross sectional area of culvert. Sediment built up in channel, tress or bushes growing in the channel.	Minor scour holes developing at inlet or outlet less than 1 ft in depth in scour hole.
3	Moderate Corrosion – deep pitting, but sound metal, flakes removed easily	Moderate Abrasion – Perforations caused by Abrasion Located within 5 feet of the Culvert inlet or outlet	Moderate – Cracks at the joint showing evidence of infiltration. Bolts missing, (10 to 15 %) deflection at the seams.	Moderate settlement and misalignment of pipe; formation of ponds of depth between 5 and 7 inches as a result of sagging, movement at joint causing offsets between ½ and 3 inches	Moderate – high flattening of the invert span of the culvert deflected less than 15%	Moderate obstruction are caused due to debris between 10-45% of the total cross sectional area of culvert, rock settlement causing rock dams, trees or bushes growing into the channel, at peak flows overtopping of roadway occurs.	Minor scour holes developing at inlet or outlet less than 3 ft in depth. Footings along the side are exposed. Damage to scour counter measures. Bottom of footing is exposed. Major stream erosion behind headwall that threatens to undermine culvert.
2	Heavy Corrosion-- deep pitting and unsound or perforated areas (unsound areas easily perforated with pointed object), Small perforations exist	Heavy Abrasion – loss of total thickness of the culvert material at the invert throughout the pipe	Opening at the joints between 1 to 3 inches causing significant infiltration and loss of backfill material at the opening, minor misalignment	Heavy Ponding greater than 7 inches in depth due to sagging or misalignment, offsets at the joints are more than 3 inches, Culvert not functioning due to alignment problems throughout.	Heavy Deflection – Span deflected between 15-20%. Much of the invert is flattened. Sharp corners at the deflected corners are observed	Heavy obstructions are caused due to settlement of debris 45%-80% of the total cross sectional area of culvert is lost, overtopping of roadway is frequent.	Major scour holes at inlet or outlet more than 3 ft in depth. Undermining cutoff walls or headwalls. Streambed degradation causing severe settlement.
1	Large perforations exist , Invert complete corroded, total or partial failure of the culvert	Loss of invert material or completely worn out. Culvert is about to collapse due to abrasion	No connection at all openings more than 3 inches, loss of alignment in series of section. Total or partial collapse of the culvert	Culvert partially collapsed or collapse in imminent, or Culvert totally collapsed.	Structure partially or totally collapsed, or ½ of the height of the structure is lost	Channel completely blocks, total loss of hydraulic capacity, road closure due to overtopping.	Total failure of culvert because of channel failure

Table 8.16: Advanced Condition Rating for Concrete Culverts

Rating	Seams or Joints	Cracking	Misalignment and Settlement	Concrete Surface	Deposits of Debris	Scouring
5	Tight Joint, No openings at the joints.	No cracking or hair cracks at the surface less than ½ ft.	Straight line between sections or minor settlements.	Concrete: no cracking, spalling, or scaling present, surface in good condition	No debris - the flow is not obstructed.	No evidence of scour at either inlet or outlet of culvert or minor scour holes developing at inlet or outlet.
4	Minor openings at the joints less than 1/2 inch, minor infiltration, loss of mortar at joints.	Minor transverse or longitudinal cracks less than 1/16 inch in width and less than 2 feet in length.	Minor misalignment at joints; offsets less than ½ inches. Minor settlement, Ponding between 3 and 5 inches at joints.	Minor hairline cracking at isolated locations; slight spalling or scaling present on invert less than 0.25 inch, minor delaminations, deep or small spalls present.	Minor waterway blockages are caused between 0-10% of the total cross sectional area of culvert. Sediment built up in channel, tress or bushes growing in the channel.	Minor scour holes developing at inlet or outlet less than 1 ft in depth in scour hole.
3	Moderate – Joints opening (less than 1 inch) due to differential movements of sections causing backfill infiltration, offset due to opening less than 4 inches, Severe loss of mortar.	Moderate transverse and longitudinal cracks having width less than 1/16 of a inch and length less than 4 ft causing little infiltration	Moderate settlement and misalignment of pipe; formation of ponds of depth between 5 and 7 inches as a result of sagging, movement at joint causing offsets between ½ and 3 inches	Cracks open greater than 0.25 in. with moderate delamination and moderate spalling, large areas of invert with surface scaling or spalls greater than 0.5 in. little efflorescence and spalling at numerous locations; spalls have exposed rebars which are heavily corroded	Moderate obstruction are caused due to debris between 10-45% of the total cross sectional area of culvert, rock settlement causing rock dams, trees or bushes growing into the channel, at peak flows overtopping of roadway occurs.	Minor scour holes developing at inlet or outlet less than 3 ft in depth. Footings along the side are exposed. Damage to scour counter measures. Bottom of footing is exposed. Major stream erosion behind headwall that threatens to undermine culvert.
2	Opening at the joints between 1 to 3 inches causing significant infiltration and loss of backfill material at the opening, offsets greater than 4 inch, minor misalignment, severe loss of mortar.	Heavy cracking throughout the circumference cracks more than 1/8 inch in width and more than 4 ft in length diagonally, backfill infiltration, displacement of section at the cracks.	Ponding depths greater than 7 inches due to sagging or Misalignment, offsets at the joints are more than 3 inches, culvert not functioning due to alignment problems throughout.	Extensive cracking, spalling, and minor slabbing; invert scaling has exposed reinforcing steel..	Heavy obstructions are caused due to settlement of debris 45%-80% of the total cross sectional area of culvert is lost, overtopping of roadway is frequent.	Major scour holes at inlet or outlet more than 3 ft in depth. Undermining cutoff walls or headwalls. Streambed degradation causing severe settlement.
1	No connection at all, loss of alignment in series of section. Total or partial collapse of the culvert.	Structure partially or totally collapsed, heavy displacement of sections at cracks, heavy backfill infiltration.	Culvert partially collapsed or collapse in imminent, or Culvert totally collapsed.	Severe slabbing has occurred in culvert wall, invert concrete completely deteriorated in isolated locations, or culvert is partially collapsed.	Channel is completely blocked, total loss of hydraulic capacity, road closure due to overtopping.	Total failure of culvert because of channel failure.

Table 8.17: Advanced Condition Rating for Plastic Culverts

Rating	Seams or Joints	Misalignment and Settlement	Shape	Deposits or Debris	Scouring
5	Tight Joint, No openings at the joints.	Straight line between sections or minor settlements.	Walls with smooth finish with deflection less than 5% of the original shape of the culvert. (Increase in span less than 5%)	No debris or deposits – The flow is not obstructed.	No evidence of scour at either inlet or outlet of culvert or minor scour holes developing at inlet or outlet.
4	Minor openings at the joints less than 1/2 inch, minor infiltration, loss of mortar at joints.	Minor misalignment at joints; offsets less than ½ inches. Minor settlement, Ponding between 3 and 5 inches at joints.	Minor bending of pipe at certain locations less than 5% of the total circumferential area having depth less than 0.25inch, and length less than 1 ft. Pipe deflection less than 10%.	Minor waterway blockages are caused between 0-10% of the total cross sectional area of culvert. Sediment built up in channel, tress or bushes growing in the channel.	Minor scour holes developing at inlet or outlet less than 1 ft in depth. Scour holes.
3	Moderate – Joints opening (less than 1 inch) due to differential movements of sections causing backfill infiltration, offset due to opening less than 4 inches, Severe loss of mortar.	Moderate settlement and misalignment of pipe; formation of ponds of depth between 5 and 7 inches as a result of sagging, movement at joint causing offsets between ½ and 3 inches	Bending of pipe at certain locations less than 10% of the total circumferential area having depth less than 0.5 inch, and length less than 3 ft. Pipe deflection less than 15%. Walls may have crushed at certain locations.	Moderate obstruction are caused due to debris between 10-45% of the total cross sectional area of culvert, rock settlement causing rock dams, trees or bushes growing into the channel, at peak flows overtopping of roadway occurs.	Minor scour holes developing at inlet or outlet less than 3 ft in depth. Footings along the side are exposed. Damage to scour counter measures. Bottom of footing is exposed. Major stream erosion behind headwall that threatens to undermine culvert.
2	Opening at the joints between 1 to 3 inches causing significant infiltration and loss of backfill material at the opening, offsets greater than 4 inch, minor misalignment, severe loss of mortar.	Ponding depths greater than 7 inches due to sagging or Misalignment, offsets at the joints are more than 3 inches, Culvert not functioning due to alignment problems throughout.	Minor bending of pipe at certain locations less than 20% of the total circumferential area having depth less than 1 inch, and length more than 3 ft. Pipe deflection less than 20%.Wall crushing.	Heavy obstruction is caused due to settlement of debris 45%-80% of the total cross sectional area of culvert is lost, overtopping of roadway is frequent.	Major scour holes at inlet or outlet more than 3 ft in depth. Undermining cutoff walls or headwalls. Streambed degradation causing severe settlement.
1	No connection at all, loss of alignment in series of section. Total or partial collapse of the culvert.	Culvert partially collapsed or collapse in imminent, or Culvert totally collapsed.	Pipe partially or totally collapsed.	Channel completely blocked total loss of hydraulic capacity, road closure due to overtopping.	Total failure of culvert because of channel failure.

8.5 Chapter Summary

This chapter discussed in detail the development of a condition assessment model for culvert asset management. At first the needs and benefits of a condition assessment model are presented. The condition assessment model is a set of protocols to identify the deteriorating culverts and is divided into two categories – Basic Condition Assessment (BCA) and Advance Condition Assessment (ACA). Basic condition assessment is the general inspection of the culvert, its components and surrounding area. A condition rating system and relative weights are developed for major culvert components to determine a performance score. Based on the performance score, the culvert is categorized into three zones – satisfactory, monitored and critical. Culverts in Critical zone are further investigated using ACA. ACA is a condition rating system developed for metal, concrete and plastic culverts. It groups the various problems according to their intensity and magnitude and assigns a condition rating. Finally, Relative weights are calculated based on the relative importance of the problems to calculate ACA performance score.

CHAPTER 9.0

PILOT STUDY

9.1 Introduction

This chapter summarizes the pilot field study of culverts conducted in Lansing, Michigan. The first step in the pilot field study was to identify the culverts for condition assessment. A request was sent to MDOT to recommend a few culverts in bad condition. MDOT suggested inspecting culverts on M 13, Shiawassee County; where about 500 culverts were on the verge of deterioration. An existing inventory list and as-built drawings of the highway M 13 was studied to find location of the culverts. First, permission from MDOT was obtained. Occupational Safety and Health Authority (OSHA) regulations were studied to ensure safety of the inspection team. According to OSHA Standard 1910.146, work within confined space is prohibited and this includes the interior of the culvert. Many workplaces contain spaces that are considered "confined" because their configurations hinder the activities of any employees who must enter, work in, and exit them. For example, employees who work in culverts generally must squeeze in and out through narrow openings and perform their tasks while cramped or contorted. OSHA uses the term "confined space" to describe such spaces. In addition, there are many instances where employees who work in confined spaces face increased risk of exposure to serious hazards. In some cases, confinement itself poses entrapment hazards. In other cases, confined space work keeps employees closer to hazards, such as asphyxiating atmospheres or the moving parts of machinery. OSHA uses the term "permit-required confined space" (permit space) to describe those spaces that both meet the definition of "confined space" and pose health or safety hazards.
(http://www.osha.gov/SLTC/confinedspaces/index.html).

9.2 Pilot Study

The inspection team looked for either the culvert marker or the roadway condition in locating the actual culvert. At the culvert site, the following step-by-step procedure was used in validating the model:

Step 1: The culvert was issued an 11-digit unique identification number based on the following details (Appendix 2):

- Route Signing Prefix
- Level of Service
- Route Number
- Directional Suffix
- Structure Number

For culvert 1, which was located on US 127 in Ingham County, the identification number was as follows:
Route Signing Prefix – US numbered highway, so code 2 as the first digit

Level of Service – Business, so code 5 as the second digit
Route Number – 127, so code 00127 as the next 5 digits
Directional Suffix – South, so code 3 as the eight digits
Structure Number – A01 was coded as the structure number as it was the first culvert in the direction of inventory
Therefore, the 11-digit unique identification number for culvert 1 is – 25001273A01. The identification number for other culverts is as shown in the Table 9.1.

Table 9.1: Unique Identification Number for Culverts

Culvert	Identification Number
2	31000131B01
3	31000131B02
4	31000131B03
5	31000131B04
6	31000131B05

Step 2: The next step was to perform the Basic Condition Assessment (BCA) using the condition rating system developed in chapter 8. The factors considered in BCA are as follows:

- Condition of the invert.
- Condition of the end treatment.
- Condition of the overall culvert.
- Condition of the roadway.
- Condition of the embankment.
- Condition of the footing.

The culvert 25001273A01 (48-in. circular CMP) located in Ingham County was scheduled for replacement in 2006. The invert was damaged (formation of a big hole, about 1’ in diameter) and corroded in few places as shown in Figure 9.1. The age deterioration was very significant. The headwall and wingwall at the culvert outlet had major spalling and cracks in few places. The embankment had moderate erosion around the structure. A layer of the concrete bed had eroded and perched due to high velocity of flowing water at the outlet. The water was flowing back at the inlet due to serious misalignment of the culvert from its design (Figure 9.2). The road above the culvert looked new and was in excellent condition. The condition rating for this culvert is as shown in the Table 9.2.

Table 9.2: Condition Rating for Culvert 25001273A01

Culvert Rating Components	Condition Rating
Condition of the Invert	1
Condition of End Treatment	3
Condition of Overall Culvert	2
Condition of Roadway	5

Condition of Embankment	3
Condition of Footing	5

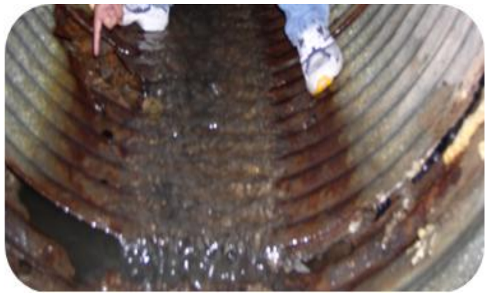


Figure 9.1: Big Hole and Corrosion in the Invert of the Culvert 25001273A01

Figure 9.2: Misalignment of the Culvert 25001273A01

The culvert 31000131B01 (24" Circular Concrete) located in Shiawassee County is about 65 years old and is in the verge of failure. Age deterioration was significant with heavy vegetation surrounding the culvert. The headwall was partially broken as shown in Figure 9.4; minor cracks and major spalling was found inside the culvert structure. Moderate misalignment of the culvert was found as shown in the Figure 9.3. The erosion around the headwall was moderate. This may be one of the reasons for headwall failure. The roadway above the culvert structure was in excellent condition. The condition rating system for this culvert is as shown in Table 9.3.

Table 9.3: Condition Rating for Culvert 31000131B01

Culvert Rating Components	Condition Rating
Condition of the Invert	2
Condition of End Treatment	1
Condition of Overall Culvert	3
Condition of Roadway	5
Condition of Embankment	3
Condition of Footing	5

Figure 9.3: Misalignment of the Culvert

Figure 9.4: Failure of the Headwall due to Heavy Spalling

The culvert 31000131B02 (24" Circular Concrete) located in Shiawassee County is also about 65 years old. The invert was eroded due to large deposition of soil sediment. The joint opening in the middle of the culvert was significant which resulted in soil infiltration and misalignment of the culvert as shown in Figure 9.5. The culvert headwall and the barrel were partially broken as shown in Figure 9.6. This can be due to heavy superimposed load or due to significant soil erosion surrounding the headwall. The culvert was surrounded by heavy vegetation, which would affect its performance. The roadway had minor settlement and cracks as shown in Figure 9.7. Overall, the culvert deterioration was very significant. The condition rating system for this culvert is as shown in the Table 9.4.

Table 9.4: Condition Rating for Culvert 31000131B02

Culvert Rating Components	Condition Rating
Condition of the Invert	3
Condition of End Treatment	1
Condition of Overall Culvert	1
Condition of Roadway	3
Condition of Embankment	2
Condition of Footing	5

Figure 9.5: Significant Misalignment of the Culvert Structure

Figure 9.6: Vegetation and Heavy Spalling in the Headwall

Figure 9.7: Cracks on the Roadway Surface

The culvert 31000131B03 (Slab – 8 ft opening, 7 ft rise; Concrete) located in Shiawassee County is also about 65 years old. Age deterioration was moderate with moderate settlement of vegetation and soil. Minor cracking was found at the construction joints between the top slab and walls. Minor infiltration on the sidewalls of the culvert is shown in Figure 9.8 Minor cracks on the roadway due to infiltration. The headwall and wingwall had hairline cracks and the embankment was eroded. The footings are in good condition. The condition rating system for this culvert is as shown in the Table 9.5.

Table 9.5: Condition Rating for Culvert 31000131B03

Culvert Rating Components	Condition Rating
Condition of the Invert	3
Condition of End Treatment	2
Condition of Overall Culvert	2
Condition of Roadway	3
Condition of Embankment	2
Condition of Footing	5

Figure 9.8: Condition of Culvert 31000131B04

The culvert structure 31000131B04 (24-in. CMP Circular) was totally failed as shown in Figures 9.9 and 9.10. The pipe was completely closed on one side. Overall, the pipe was corroded inside and outside. The roadway had a pothole and moderate cracks due to culvert deterioration. The embankment is partially eroded. The culvert had no end treatment. The condition rating for this culvert is as shown in the Table 9.6.

Table 9.6: Condition Rating for Culvert 31000131B04

Culvert Rating Components	Condition Rating
Condition of the Invert	2
Condition of End Treatment	5
Condition of Overall Culvert	1
Condition of Roadway	1
Condition of Embankment	3
Condition of Footing	5

Figure 9.9: Corrosion on the Outside Surface of the CMP

Figure 9.10: Total Failure of the Culvert End

The culvert 31000131B05 (Slab – 8 ft opening and 7 ft rise) is located in Shiawassee County and is about 65 years old. This culvert is deteriorated, but functioning normal. Moderate deposition of soil sediments over the invert, headwall and wingwall was heavily damaged with spalling. This has led to heavy corrosion of the reinforcing bars. There is minor cracking between the footing and wingwall; the roadway above the culvert has potholes and major cracks. The embankment was heavily eroded. The condition of the footing looks good. Overall, the culvert was in poor condition. The condition rating for this culvert is as shown in the Table 9.7.

Table 9.7: Condition Rating for Culvert 31000131B05

Culvert Rating Components	Condition Rating
Condition of the Invert	2
Condition of End Treatment	5
Condition of Overall Culvert	1
Condition of Roadway	1
Condition of Embankment	3
Condition of Footing	5

Figure 9.11: Condition of Culvert Structure 31000131B05

Step 3: The third step in this process is to calculate the performance score of the culverts and categorize them in three zones – Satisfactory (Green), Monitored (Yellow) and Critical (Red).

The calculation of relative weights of the different components affecting the performance of the culvert is explained in Chapter 8 and is as shown in Table 9.9. The performance score is calculated by multiplying the condition rating of each component with their respective relative weight and finally summing up all the values. The performance score for culvert 25001273A01 is as shown in Table 9.8 below:

Table 9.8: Performance Score Calculation for Culvert 25001273A01

Culvert 25001273A01	Condition Rating	Relative weight	Performance Score
Condition of the Invert	1	0.21964	0.21964
Condition of End Treatment	3	0.14043	0.42130
Condition of Overall Culvert	2	0.38877	0.77753
Condition of Roadway	5	0.05826	0.29129
Condition of Embankment	3	0.06302	0.18906
Condition of Footing	5	0.12988	0.64941
Final Performance Score			**2.54824**

The final performance score for culvert 25001273A01 is 2.55. This culvert will be categorized under the yellow or intermediate zone for short and long term planning. Similar calculation is done for other culverts and categorized as shown in Table 9.9.

Table 9.9: Performance Score Calculation and Zoning for Inspected Culverts.

Culvert Identification Number	Performance Score	Zone
31000131B01	2.876	Monitored
31000131B02	2.138	Critical
31000131B03	2.688	Monitored
31000131B04	2.427	Critical
31000131B05	2.427	Critical

The final step in the validation process was to identify the culverts in danger zone and calculate the advanced condition assessment (ACA) performance score. The culverts in Critical zone are inspected in detail for specific problems and given a condition rating between 5-0 (APPENDIX), where 5 is excellent or new condition and 0 is complete failure. The ACA performance score is calculated in the same way as BCA as shown in previous step. The ACA is inspection of the culvert barrel; if the culvert is not functioning or totally damaged, then ACA performance score will be zero. Since, the culvert 31000131B04 was totally collapsed, the ACA performance score is calculated as zero. The calculation of ACA performance score for culverts 31000131B02 and 31000131B05 are as shown in Table 9.10 and 9.11.

Table 9.10: ACA Performance Score Calculation for Culvert 31000131B02.

Culvert 31000131B02	ACA Condition Rating	ACA Relative Weight	ACA Performance Score
Cracking	2	0.3285	0.6340
Scouring	5	0.1478	0.8515
Settlement	2	0.1478	0.3126
Joint Problem	1	0.1571	0.1521
Misalignment	1	0.1571	0.1348
Concrete Surface	4	0.0616	0.2760
Final Performance Score			**2.2525**

Table 9.11: ACA Performance Score Calculation for Culvert 31000131B05.

Culvert 31000131B05	ACA Condition Rating	ACA Relative Weight	ACA Performance Score
Cracking	1	0.3170	0.3170
Scouring	4	0.1703	0.6812
Settlement	2	0.1563	0.3126
Joint Problem	3	0.1521	0.4563
Misalignment	4	0.1348	0.5392
Concrete Surface	3	0.0690	0.2070
Final Performance Score			**2.5002**

9.3 Chapter Summary

This phase of the study was the validation of the developed models by conducting field pilot study in Lansing, Michigan. Six culvert sites were identified for the field study, one in Ingham County and other five in Shiawassee County. All the culverts were given a unique identification number as a part of inventory study. Then, basic condition assessment was carried out and performance scores for all culverts were calculated. Based on the performance score, the culverts were categorized into Green (Satisfactory), Yellow (Monitored) and Red (Critical) zones. The culverts under red zone were further investigated to calculate the ACA condition rating and performance score. The summary of the investigation is shown in Table 9.12.

Table 9.12: Summary of the Pilot Field Study.

Culvert No.	County	Shape	Material	Span (in.)	BCA Score	Zone	ACA Score	Year Built
25001273A01	Ingham	Circular	CMP	48	2.548	Monitored	-	-
31000131B01	Shiawassee	Circular	Concrete	24	2.876	Monitored	-	1931
31000131B02	Shiawassee	Circular	Concrete	24	2.138	Critical	2.253	1931
31000131B03	Shiawassee	Slab	Concrete	96	2.688	Monitored	-	1931
31000131B04	Shiawassee	Circular	CMP	24	2.427	Critical	0	1931
31000131B05	Shiawassee	Slab	Concrete	96	2.427	Critical	2.5002	1931

CHAPTER 10.0

CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusions

State Departments of Transportations (DOTs) are facing severe and rising needs of renewing heavily deteriorated infrastructure. Further challenges for DOTs are the wide geospatial distribution of infrastructure assets and environmental exposure. While the challenges are well understood, budget allocations and resources limitations represent a major barrier to a comprehensive asset management program.

To respond to these challenges, this project was performed to evaluate and document culverts and drainage structures and to study optimal ways of inspection, maintenance, and operation with modern information technologies. The specific objectives of the project were to develop inventory and condition assessment protocols and business rules for culvert structures, and to validate and optimize above protocols and business rules based on field pilot studies in Michigan and Ohio.

As a part of this project, the inventory and inspection procedures in Ohio were examined and a decision support platform which connects the outcome of culvert inspections that are performed according to ODOT Culvert Management Manual with the possible repair, renewal and replacement methods was developed. The Culvert Management Manual published by Ohio Department of Transportation provides highly detailed inventory and inspection procedures which may be implemented by other DOTs that do not yet have standardized culvert inventory and inspection procedures after modifying them due to the needs and environmental characteristics of these particular states.

The investigators completed the following tasks for this project:

1. Reviewed of existing literature and conduct a national survey of best practices on drainage structures and culvert asset management efforts among the 50 state (specially the Midwestern states) DOTs and 10 Canadian provinces. This review included study of drainage structures by size, age, installation data, material type, soil condition, climate, traffic frequency, and loading. We developed an optimal classification methodology for MDOT and ODOT inventory.
2. Reviewed of various hydraulic, land-use changes and mechanical factors affecting the deterioration of drainage structures. Collected information was checked against MDOT and ODOT documented history of failed, repaired, as-built and replaced drainage structures and culverts.
3. Reviewed of existing inspection, data analysis and reporting methods for drainage structures and culverts and study of the modifications to buried pipes technologies to be implemented on drainage structures and culverts.
4. Developed an inventory and inspection protocols and business rules for MDOT and ODOT engineers and field operators. The procedure outlined the steps to be

followed during an inspection mission and the required information to be recorded when a given structure is to be added to the inventory system. The resulting protocol and business rule workbook were designed to be used in existing MDOT and ODOT asset management programs.

5. Synthesized the research findings into a platform for a decision support system for culvert inspection, renewal, maintenance, and asset management.
6. Performed pilot studies in Michigan to validate the protocol and decision support platform.
7. Collaborated with MDOT and ODOT engineers to write a section on inventory and inspection to be added to current best practices and business rules manuals.
8. Wrote a final report documenting all research findings.
9. Wrote several papers and articles to disseminate research results specifically for use of other Midwest states.
10. Prepared slide presentations to disseminate results of this research to DOT personnel.

10.2 Recommendations for Future Study

Culverts have the peculiarity of being characterized as both buried pipes in small diameters with no access and worker entry and larger ones with possibility of manual inspection and repair/renewal. As such, asset management procedures for culverts are a complex issue, and can benefit a great deal from an optimal asset management program that incorporates new trenchless technologies. Trenchless technologies are not disruptive to transportation systems and provide safer construction operations for both workers and the public. If they are used at appropriate application, they provide a new design life to existing culverts and drainage structures that may double or triple the original design life of these assets. However, trenchless technologies are many and some of these methods are new, and while viable, have little field performance history in culverts and transportation systems. Each method has its own capabilities and limitations, and can be applied in certain existing conditions to be effective.

As mentioned previously, authors are working on another MRUTC Project in which the usage of trenchless technologies for a comprehensive asset management of culverts will be investigated. This second phase will provide the opportunity to select the best trenchless renewal and replacement techniques once the condition of the culvert is identified. The choice of trenchless culvert and drainage structure renewal methods depends on the physical conditions of the existing culvert and drainage structure system, such as culvert and drainage structure length, type, material, size, type, and the nature of the problem or problems involved. The problems with existing culvert may include structural or non-structural, as well as hydraulic problems. Other features of the renewal systems, such as, applicability to a specific project, constructability, cost factors, and life expectancy should be considered in developing a comprehensive asset management program (Najafi and Osborn, 2008).

The results of the second project will complement the decision platform provided in this project. With the completion of the second phase, it will be easier to identify the trenchless options which will provide the solution to the given culvert conditions and to compare it with the other repair methods or in case of replacement with the open cut method.

CHAPTER 11.0

GLOSSARY

Ablation The process by which ice and snow waste away from melting and evaporation or by which land wears away by the action of surface water.

Abrasion Wearing or grinding of material by water laden with sand, gravel or stones.

Absorption The assimilation or taking up of water or other solutions by soil or other material, the entrance of water into the soil or rocks by all natural processes. It includes the infiltration of precipitation or snowmelt; gravity flow of streams into the valley alluvium (see storage, bank), sinks, or other large openings; and the movement of atmospheric moisture.

Abstraction That portion of rainfall that does not become runoff. It includes interception, infiltration, and storage in depressions. It is affected by land use, land treatment and condition, and antecedent soil moisture.

Abutment The superstructure support at either end of a bridge or similar type structure, usually classified as spill through or vertical. Considered part of the bridge substructure.

Acidic The substances with a pH less than 7.0 which may react with or corrode certain metals. Soils or water may be acidic and react with metal culverts.

Aggradation It is the process of general and progressive rising of the streambed by deposition of sediment.

Afflux Backwater or height by which water levels are raised at a stated point, owing to presence of a constriction or obstruction, such as a bridge.

Algae Any of various primitive, chiefly aquatic, one-celled or multi-cellular plants that lack true stems, roots, and leaves but usually contain chlorophyll.

Alkaline Substances having pH greater than 7.0 such substances are caustic or able to corrode.

Allowable Headwater	Difference in elevation between the flowline of the culvert and the lowest point in which the water surface at upstream would either flood the highway or jeopardize the property.
Alluvial	Referring to deposits of silts, sands, gravels, or similar detritus material that has been transported by running water.
Anode	A metallic surface on which oxidation occurs, giving up electrons with metal ion going into solution or forming an insoluble compound of the metal.
Amphibian	Any of the various cold-blooded, smooth-skinned vertebrate (with backbone) organisms such as toads, frogs, and salamanders, characteristically hatching as an aquatic larvae that breathe by means of gills and metamorphosing to an adult form having air-breathing lungs.
Angle of Flare	Angle between direction of wingwall and the centerline of a culvert barrel.
Angle of repose	The maximum angle, as measured from the horizontal, at which granular particles can stand.
Angularity	The acute angle between the plane of the highway centerline along the bridge, and a line normal to the thread of the stream, i.e., the acute angle between the thread of the stream and a line normal to the centerline along bridge.
Antidune	A particular type of bed form caused by water flowing over a mobile material such as sand.
Apex	The highest point, the vertex.
Approach Channel	The reach of channel upstream from a dam, bridge constriction, culvert, or other drainage structure.
Apron	Protective material laid on a streambed to prevent scour commonly caused by some drainage facility or a floor lining of such things as concrete, timber, and riprap, to protect a surface from erosion.
Aqueduct	An open or closed channel used to convey water, or an open conduit of things such as wood, concrete, or metal on a prepared grade, trestle, or bridge.
Area Rainfall	Average rainfall of the area.
Arid	Geographic areas that are dry, lacking moisture. Compare with desert and semi-arid.

Armoring	A natural process whereby an erosion-resistant layer of relatively large particles is formed on a channel bank and/or channel bed due to the removal of finer particles by stream flow, i.e., the concentration of a layer of stones on the bed of the stream that are of a size larger than the transport capability of the recently experienced flow—the winnowing out of smaller material capable of being transported while leaving the larger sizes as armor that, for discharges up to that point in time, cannot be transported.
Augmented Flow	The increased volume of water entering a channel, or allowed to run overland as waste waters from the diversion of surface flow or as water from another stream or watershed; or from waters withdrawn or collected upstream and released after use.
Autogeneous Healing	A process where small cracks are healed by exposure to moisture, forming calcium carbonate crystals that accumulate along the crack edges, inter twining and building until the crack is filled.
Backfill	The material used to refill the trench or the embankment placed over the top of the bedding and culvert.
Backwater	The water upstream from an obstruction in which the free surface is elevated above the normal water surface profile.
Baffle	A structure constructed on the bed of a stream or drainage facility to deflect or disturb the flow. Vanes or guides, a grid, grating, or similar device placed in a conduit to check eddy currents below them, and effect a more uniform distribution of velocities. Also a device used in a culvert or similar structure to facilitate fish passage.
Bank	The side slopes or margins of a channel between which the stream or river is normally confined. More formally, the lateral boundaries of a channel or stream, as indicated by a scarp, or on the inside of bends, by the stream ward edge of permanent vegetal growth.
Bar	It is an elongated deposit of alluvium, not permanently vegetated, within or along the side of a channel.
Barrage	See Check Dam.
Barrel Width	Commonly the inside, horizontal extent of a drainage facility.
Base	The layers of specified material placed on the sub base or sub grade to support the pavement, surface course, or a drainage facility.
Base Flow	In the U.S. Geological Survey's annual reports on surface-water supply, the discharge above which peak discharge data are published. The base discharge at each station is selected so that an average of approximately three peaks a year will be presented.

Basic Hydrologic Data — Includes inventories of land and water features that vary only from place to place (topographic and geologic maps are examples) and records of processes that vary with both place and time (records of precipitation, stream flow, groundwater, and quality-of-water analyses are examples).

Basin, Detention — A basin or reservoir incorporated into the watershed whereby runoff is temporarily stored, thus attenuating the peak of the runoff hydrograph.

Bedding — The soil used to support the load on the pipe. For, rigid pipe, the bedding distributes the load over the foundation. It does the same thing for the flexible pipe except that it is not as important a design factor.

Bedload — The sediment that is transported in a stream by rolling, sliding, or skipping along the bed or very close to it; considered to be within the bed layer.

Bed — The bottom of a channel. The part of a channel not permanently vegetated which is bounded by banks and over which water normally flows.

Bed Layer — A flow layer, several grain diameters thick (usually two) immediately above the bed.

Bed Material — The sediment mixture of which a streambed, lake, pond, reservoir, or estuary bottom is composed.

Bedrock — The scour-resistant material underlying erodible soils and overlying the mantle rock, ranging from surface exposure to depths of several hundred miles.

Bed Slope — The longitudinal inclination of a channel bottom

Bench-Flume — A conduit on a topographical bench, cut into sloping ground. Compare with flume.

Best Management Practices (BMPs) — Erosion and pollution control practices employed during construction to avoid or mitigate damage or potential damage from the contamination or pollution of surface waters or wetlands from a highway action.

Bituminous Mattress — An impermeable rock-, mesh-, or metal-reinforced layer of asphalt or other bituminous material placed on a channel bank to prevent erosion.

Blanket — Material covering all or a portion of a channel bank to prevent erosion. Stream bank surface covering, usually impermeable, designed to serve as protection against erosion. Common pavements used on channel banks are concrete, compacted asphalt, and soil-cement.

Bore Hydraulic — A wave of water having a nearly vertical front, such as a tidal wave, advancing upstream as a result of high tides in certain estuaries; a similar wave advancing downstream as the result of a "cloudburst," or the sudden release of a large volume of water from a reservoir, as in the Johnstown (PA) flood.

Bottom Contraction — Channel contraction resulting from some protrusion across the bottom of a channel.

Boulder — A rounded or angular fragment of rock, the diameter of which is in the size range of 250 mm to 4000 mm (10 in. to 160 in.) according to FHWA Highways in the River Environment Manual.

Box Section — A concrete or corrugated pipe with a rectangular or nearly rectangular cross section.

Braid — A subordinate channel of a braided stream. See stream, braided. Compare with anabranch.

Breakers — It is the surface discontinuities of waves as they breakup. They may take different shapes (spilling, plunging, surging). Zone of break-up is called the surf zone.

Bridge — A structure including supports erected over a depression or an obstruction, such as water, highway, or railway, and having a tract or passageway for carrying traffic or moving loads, and, for definition purposes (AASHTO), having an opening measured along the center of the roadway equal to or more than 6.1 m (20 ft) between under copings of abutments or spring lines of arches, or extreme outside ends of openings for multiple boxes; it may also include multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening.

Bridge Opening — The total cross section area beneath a bridge superstructure that is available for the conveyance of water. Compare with bridge waterway.

Bridge Waterway — The area of a bridge opening available for flow as measured below a specified stage and normal to the principal direction of flow. Compare with bridge opening.

Buckling — Failure by an inelastic change in alignment.

Buried Pipe — A structure that incorporates both the properties of the pipe and properties of the soil surrounding it.

Buoyancy — The upward force exerted by a fluid on a body in it.

Canal — A constructed open conduit or channel for the conveyance of irrigation water that is distinguished from a ditch or lateral by its larger size. It is usually excavated in natural ground, although lined canals on berms are not uncommon.

Capacity — The maximum flow rate that a channel, conduit or structure is hydraulically capable of carrying. The units are usually CFS or GPM.

Catch Basin — The structure, sometimes with a sump, for inletting drainage from such places as a gutter or median and discharging the water through a conduit. In common usage it is a grated inlet, curb opening, or combination inlet with or without a sump.

Cathode — The surface that accepts electrons and does not corrode.

Cathodic Protection — Preventing metal from eroding. This is done by making the metal a cathode through the use of impressed direct current or by attaching a sacrificial anode.

Cavitation — A phenomenon associated with the vaporization of the flowing liquid at high velocities in a zone of low pressure, wherein cavities filled with liquid alternatively develops and collapse; surface pitting of a culvert may arise.

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

CFS — Rate of flow in cubic feet per second.

Channel — The bed and banks that confine the flow of surface water in a natural stream or artificial channel; also see river and stream or the course where a stream of water runs or the closed course or conduit through which water runs, such as a pipe.

Channelization — Straightening and/or deepening of a channel by such things as artificial cutoffs, grading, flow-control measures, river training, or diversion of flow into an artificial channel.

Chlorides — Binary chemical compounds containing chlorine which can corrode concrete reinforcing steel.

Check Dam — A relatively low dam or weir across a channel for the diversion of irrigation flows from a small channel, canal, ditch, or lateral. A check dam can also be a low structure, dam, or weir, across a channel for such things as the control of water stage or velocity or the control of channel bank erosion and channel bed scour from such things as head cutting.

Chemical Stabilization — It is the process of applying of chemical substances to increase particle cohesiveness and to shift the size distribution toward the coarser fraction. The net effect is to improve the erosion resistance of the material.

Chute
An open or closed channel used to convey water, usually situated on the ground surface.

Cladding
It is aluminum culvert sheet sandwich with aluminum magnesium – manganese alloy 3004 between two layers of aluminum – zinc alloy 7072 cladding for corrosion protection.

Class
The grade or quality of pipe.

Coating
Any material used to protect the integrity of the structural elements of a pipe from the environment and add service life to culvert.

Coefficient of Contraction
The ratio of smallest cross sectional area of the flow after passing the constriction to the nominal cross section area of the constriction.

Coefficient of Discharge
Ratio of observed to theoretical discharge. Also the coefficient used for orifice or other flow processes to estimate the discharge past a point or through a reach.

Compaction
The process by which a sufficient amount of energy is applied to soil to achieve a specific density.

Conductivity
Is a measure of the corrosive potential of soils, which is expressed in milli-mhos per centimeter. It is the reciprocal of resistivity.

Conductor
Is a metallic connection that permits electrical current flow by completing the circuit.

Conduit
Usually a pipe, designed to flow according to open flow equations.

Conveyance
A measure of the ability of a stream, channel, or conduit to convey water or a comparative measure of the water-carrying capacity of a channel; that portion of the Manning discharge formula that accounts for the physical elements of the channel.

Corrosion
Deterioration or dissolution of a material by a chemical or electrochemical reaction with its environment.

Cover
The depth of backfill over the top of the pipe.

Crack
A fissure in an installed precast concrete culvert.

Critical Depth
Critical depth is the depth at which the specific energy of a given flow rate is at a minimum. For a given discharge and cross – section geometry, there is only one critical depth.

Critical Flow	The flow in open channels or conduits at which the energy content of the fluid is at a minimum.
Critical Velocity	Mean velocity (V_c) of flow at critical depth (d_c); in open channels the velocity head equals one-half the mean depth.
Cross Drainage	It is the runoff from contributing drainage areas both inside and outside the highway right-of-way and the transmission thereof from the upstream side of the highway facility to the downstream side.
Crown	The top side of the culvert.
Culvert	Is a structure that is usually designed hydraulically to take advantage of submergence to increase hydraulic capacity; a structure used to convey surface runoff through embankment.
Dam	A barrier to confine or raise water for storage or diversion, or to create a hydraulic head.
Debris	Any material including floating woody materials and other trash, suspended sediment, or bed load moved by a flowing stream.
Deflection	Change in the original or specified inside diameter of pipe.
Degradation	Process of general progressive lowering of the stream channel by erosion.
Depletion	Is the progressive withdrawal of water from surface or groundwater reservoirs at a rate greater than that of replenishment.
Deposition	Settling of material from the stream flow onto the bed.
Design Discharge	The maximum rate of flow (or discharge) for which a drainage facility is designed and thus expected to accommodate without exceeding the adopted design constraints.
Detour	A temporary change in the roadway alignment. It may be localized at a structure or may be along an alternative route.
Discharge (Q)	Flow from a culvert, sewer or channel in CFS.
Drainage	The interception and removal of ground water or surface water by artificial or natural means.
Drainage Area	The catchment area for rainfall and other forms of precipitation that is delineated as the drainage area producing runoff, i.e., contributing drainage area. Usually it is assumed that base flow in a stream also comes from the same drainage area.

Drainage Basin	A part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water
Drop Inlet	Type of inlet structure that conveys water from higher elevation to a lower outlet elevation smoothly without a free fall at the discharge.
Durability	The ability to withstand corrosion and abrasion over time or service life.
Embankment	A bank of earth, rock or material constructed above the natural ground surface over a culvert.
End Section	A concrete or steel appurtenance attached to the end of a culvert for the purpose of hydraulic efficiency and anchorage.
Energy Dissipator	Device to decrease hydraulic energy placed in ditches or culvert outfalls to reduce streambed scour.
Energy Gradient	The increase or decrease in total energy of flow with respect to distance along the channel.
Energy Grade Line	The line which represents the total energy gradient along the channel. It is established by adding together the potential energy expressed as the water surface elevation referenced to a datum and the kinetic energy at points along the stream bed or channel floor.
Environmental Effects	Pertaining to the effects of highway engineering works on their surroundings and on nature.
EPA	Environmental Protection Agency.
Erosion (Culvert)	Wearing o grinding away of culvert material by water laden with sand, gravel or stones; generally referred to as abrasion.
Erosion (Stream)	The process of the wearing of the streambed by flowing water.
Exfiltration	The process by which storm water leaks or flows to the surrounding soil through such things as openings in a conduit, channel banks, or lake shores.
FHWA	Federal Highway Administration.
Filtration	The process of passing water through a filtering medium consisting of either granular material or filter geo textiles for the removal of suspended or colloidal matter.

Fish Passage	Ability of fish to pass through bridge and culvert structure.
Flexible Pipe	A pipe with relatively little resistance to bending i.e. as the load increases the vertical diameter decreases and the horizontal diameter increases, which is resisted by the soil around the pipe.
Flood	In common usage, an event that overflows the normal flow banks or runoff that has escaped from a channel or other surface waters.
Flood Frequency	The number of years, on the average, within which a given discharge will be equaled or exceeded.
Flow	A stream of water; movement of such things as water, silt and/or sand; discharge; total quantity carried by a stream.
Flow Line	A line formed by the invert of pipe.
Flow Regime	The system or order characteristic of stream flow with respect to velocity, depth, and specific energy.
Flow Steady	A flow in which the flow rate or quantity of fluid passing a given point per unit of time remains constant or a constant discharge with respect to time.
Flow Subcritical	In this state, gravity forces are dominant so that the flow has a relatively low velocity and is often described as tranquil or streaming and the flow that has a Froude number less than unity.
Flow Supercritical	In this state, inertia forces are dominant so that flow has a high velocity and is usually described as rapid or shooting and the flow that has a Froude number greater than unity.
Flow Turbulent	The flow condition in which inertial forces predominate over viscous forces and in which head loss is not linearly related to velocity.
Flow Uniform	Flow of constant cross section and average velocity through a reach of channel during an interval of time. It is also a constant flow of discharge, the mean velocity of which is also constant.
Foundation	It is the material beneath the pipe.
Freeboard	It is the vertical clearance between the lowest structural member of the bridge superstructure, the top culvert invert, or the point of escape in a canal or channel to the water surface elevation of a flood.
Free Flow	A condition of flow through or over a structure not affected by submergence.

Free Outlet	A free outlet has a tailwater equal to or lower than critical depth. For culverts having free outlets, lowering of the tailwater has no effect on the discharge or the backwater profile upstream of the tailwater.
Froude Number	A dimensionless number (expressed as F = V/(gy)1/2) that represents the ratio of inertial to gravitational forces, i.e., at a Froude number of unity the flow velocity and wave celerity are equal
Galvanizing	It is the process of applying of a thin layer of zinc to steel by hot dipping.
Gauge	Thickness of sheet metal used in corrugated metal pipe.
Grade	The longitudinal slope of the channel as a ratio of the drop in elevation to the distance.
Gradient	See Grade.
Gravel	The particles, usually of rock, whose diameter is between 2 mm and 100 mm (0.08 in. and 4.0 in.).
Groundwater	Water contained in the subsoil, which is free to move either vertically or horizontally.
Groundwater runoff	That part of the runoff that has passed into the ground, has become groundwater, and has been discharged into a stream channel as spring or seepage water.
Grout	A fluid mixture of cement and water or of cement, sand, and water used to fill joints and voids.
Hairline Cracks	Very small cracks that form in the surface of the concrete pipe due to tension caused by loading.
Head	The height of water above any point, plane, or datum of reference. Used also in various computations, such as energy head, entrance head, friction head, static head, pressure head, lost head, etc.
Headloss	The loss of energy reported in feet of head.
Head Velocity	The distance a body must fall freely under the force of gravity to acquire the velocity it possesses; the kinetic energy, in meters [feet] of head, possessed by a given velocity.
Headwall	A concrete structure placed at the inlet and outlet of a culvert to protect the embankment slopes, anchor the culvert and prevent undercutting.

Headwater	It is the distance between the flowline elevation at the inlet of a culvert and the water surface at the inlet.
Holidays	Defect in protective coating on metal surface.
Hydraulics	The mechanics of fluids, mainly water.
Hydraulic Gradeline	An imaginary line, representing the total energy and paralleling the free water surface if the flows were at atmospheric pressure.
Hydraulic Friction	A force resisting flow that is exerted on contact surface between a stream and its containing channel.
Hydraulic Jump	An abrupt rise in the water surface in the direction of flow when the type of flow changes from supercritical to subcritical.
Hydraulic Radius	The cross-sectional area of flow divided by the length of that part of its periphery in contact with its containing conduit; the ratio of area to wetted perimeter.
Hydrology	The science of water related to its properties and distribution in the atmosphere, on the land surface, and beneath the surface of the land.
Improved Inlet	An improved inlet has an entrance geometry that decreases the flow constriction at the inlet and thus increases the capacity of the culverts.
Impermeable Strata	It is a stratum in which texture is such that water cannot move perceptibly through it under pressures ordinarily found in subsurface water.
Impervious	It is impermeable to the movement of water.
Impingement	Suspended solid particles or gas bubbles in water striking the surface or turbulence along breaking down the protective layer of a metal or a concrete surface.
Infiltration	The flow of a fluid into a substance through pores or small openings. It connotes flow into a substance in contradistinction to the word percolation, which connotes flow through a porous substance.
Inflow	The rate of discharge arriving at a point (in a stream, structure, or reservoir).
Inversion Lining	Process of inverting pliable tube into existing pipe with hydrostatic or air pressure to reline existing pipe. The tube is forced against the existing pipe and thermosetting resins to provide structural strength and improved smoothness.

Invert	The invert is the flowline of a culvert (inside bottom) or the flow line in a channel cross section, pipe, or culvert or the lowest point in the channel cross section or at flow-control devices such as weirs or dams.
Inundate	To cover or fill as with a flood.
Joint	A connection between two pipe sections made either with or without the use of additional parts.
Lateral	A conduit, ditch, canal, or channel conveying water diverted from a main conduit, canal, or channel for delivery to distributaries; sometimes considered a secondary ditch.
Launching	Release of undercut material (stone riprap, rubble, slag, etc.) down slope; if sufficient material accumulates on the stream bank face, the slope can become effectively armored.
Link Pipe Lining	Method of pulling a short, pipe line segment to the damaged point in an existing pipe and jacking the segment into place.
Load (or sediment load)	The amount of sediment being moved by a stream.
Long Span Culverts	These culverts are designed on structural aspects rather than hydraulic considerations. Usually constructed of structural plates, which exceed defined sizes for pipes, pipe arches, arches or special shape that involve a long radius or curvature in the crown or side plates.
Manning's Equation	An equation for the empirical relationship used to calculate the barrel friction loss in culvert design.
Meander	The winding of a stream channel. Any reverse or letter-S channel pattern fashioned in alluvial materials by erosion of the concave bank, which is free to shift its location and adjust its shape as part of a stage in the migratory movement of the channel as a whole down an erodible, alluvial valley.
Metal Corrosion	It is an electrical process involving an electrolyte (moisture), an anode (the metallic surface where oxidation occurs), a cathode (the metallic surface that accepts electrons and does not corrode), and a conductor (the metal pipe itself).
Minor Head Losses	Head lost through transitions such as entrances, outlets, obstructions, and bends.
Moisture	Water diffused in the atmosphere or the ground.
Normal Flow	Normal flow occurs in a channel reach when the discharge, velocity and depth of flow do not change throughout the reach. The water

	surface profile and channel bottom slope will be parallel. This type of flow will exist in a culvert operating on a steep slope provided the culvert is sufficiently long.
Outfall	The discharge end of drains or sewers.
Outlet Control	A condition where the relation between headwater elevation and discharge is controlled by the conduit, outlet, or downstream conditions of any structure through which water may flow.
Parameter	A characteristic descriptor, such as a mean or standard deviation or sometimes considered as a variable comprised of the product of two or more variables.
Peak Discharge	The highest value of the stage or discharge attained by a flood; thus, peak stage or peak discharge.
Permeability	The property of a material that permits appreciable movement of water through it when it is saturated and movement is actuated by hydrostatic pressure of the magnitude normally encountered in natural subsurface water.
Perforation	Complete penetration of metal culvert that generally occurs in the invert.
pH Value	The log of the reciprocal of the hydrogen ion concentration of a solution. The pH value of 7.0 is neutral; values of less than 7.0 are acid; values of more than 7.0 are basic.
Pipe	A tube or conduit.
Pipe Diameter	The inside diameter of a pipe.
Piping Action	A process of subsurface erosion in which surface runoff flows along the outside of a culvert and with sufficient hydraulic gradient erodes and carries away soil around or beneath the culvert.
Polyethylene Pipe	Plastic pipe manufactured from polymerized ethylene in corrugated or smooth configurations of various dimensions.
Polymer Coating	A protective coating of plastic polymer resins with other materials.
Ponding	Water back up in a channel or ditch as the result of a culvert of inadequate capacity or design to permit the water to flow unrestricted.
Reinforced Concrete Pipe	A concrete pipe designed with reinforcement as a composite structure.
Rigid Pipe	A pipe with high resistance to bending.

Riprap	Rough stones of various sizes placed compactly or irregularly to prevent scour by water or debris.
Roughness Coefficient (n)	A factor in the Kutter, Manning, and other flow formulas representing the effect of channel roughness upon energy losses in flowing water.
Resistivity (Soil)	An electrical measurement in ohm-cm, which is one of the factors for estimating the corrosiveness of a given soil to metal.
Runoff	That part of precipitation carried off from the area upon which it falls.
Sacrificial Coating	A coating over the base material to provide protection to the base material. Examples include galvanizing on steel and cladding on aluminum.
Sacrificial Thickness	Additional pipe thickness provided for extra service life of the culvert in an aggressive environment.
Scour (outlet)	The process of degradation of the channel at the culvert outlet as a result of erosive velocities.
Seepage	It is the process of escaping of water through the soil, or water flowing from a fairly large area of the soil instead of from one spot, as in the case of a spring.
Shotcrete Lining	Application of pneumatically applied cement plaster or concrete to an in place structure to increase structural strength and improve the surface smoothness.
Skew	The acute angle formed by the intersection of the line normal to the centerline of the road with the centerline of a culvert or other structure.
Slabbing	The radial tension failure of concrete pipe resulting from the tendency of curved reinforcing steel or cage to straighten out under the load.
Slide	Movement of a part of the earth under the force of gravity.
Sliplining	The process of placing a smaller diameter pipe in a larger diameter existing pipe to improve the culvert structure and repair leaks. The annular space between the pipes is usually filled with grout.
Slope	Steep slopes occur where the critical depth is greater than the normal depth.
Spelter	Zinc slabs or plates.

Spalling (Culvert)	The separation of surface concrete due to fractures in the concrete parallel or slightly inclined to the surface of the concrete.
Springline	The points on the internal surface of the transverse cross section of a pipe intersected by the line of maximum horizontal dimension; or in box sections, the mid height of the internal vertical wall.
Structural Plate	Plates of structural steel used to fabricate large culvert structures such as arches or boxes.
Submerged Inlet	A submerged inlet occurs where the headwater is greater than 1.2D.
Submerged Outlet	A submerged outlet occurs where the tailwater elevation is higher than the crown of the culvert.
Sulfates	Chemical compounds containing SO4 found in alkaline soils that cause concrete deterioration.
Tailwater Depth	The depth of water just downstream from a structure.
Trenchless Renewal	It is the process of Upgrading to a new design life by forming a new pipe within the existing pipe with minimum or no excavation.
Trenchless Replacement	Upgrading to a new design life by destroying the existing pipe and installing a new pipe with minimum or no excavation.
Velocity Head	For water moving at a given velocity, the equivalent head through which it would have to fall by gravity to acquire the same velocity.
Watercourse	A channel in which a flow of water occurs, either continuously or intermittently, with some degree of regularity.
Weir	A man made barrier in an open channel over which water flows. It is used to measure the quantity of flow.
Wetted Perimeter	The length of the wetted contact between the water and the containing conduit measured at right angles to the conduit.

CHAPTER 12.0
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APPENDIX -1

CULVERT INVENTORY PROTOCOL

CULVERT INVENTORY PROTOCOL

This appendix presents the details of a culvert inventory protocol developed by authors.

A 1.1 GENERAL INFORMATION

1. Date of Inventory:	2. Name of the Person:
3. State Code:	4. Country Code:
5: Place Code:	6. Inventory Code:
7. Functional Classification:	8. Mile Marker
9. Year Built	10. Latitude
11. Longitude	12. Maintenance Responsibility:
13. ADT:	14. Approach Roadway Width:
15. Culvert Marker:	

A 1.2 STRUCTURAL INFORMATION

Barrel

16. Shape	17. Material:
18. Number of Cells	19. Length *

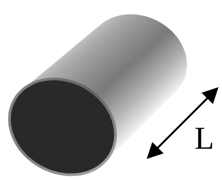


Figure A1.1: Length of the barrel

Geometric Dimensions

Please enter relevant dimensions according to shape; refer figure below for standard dimensions.
Note: All dimensions in feet and inches.

20. Diameter:	21. Span	22. Rise:

23. R_t = ______________________

24. R_c = ______________________

25. R_s = ______________________

26. R_b = ______________________

27. R = ______________________

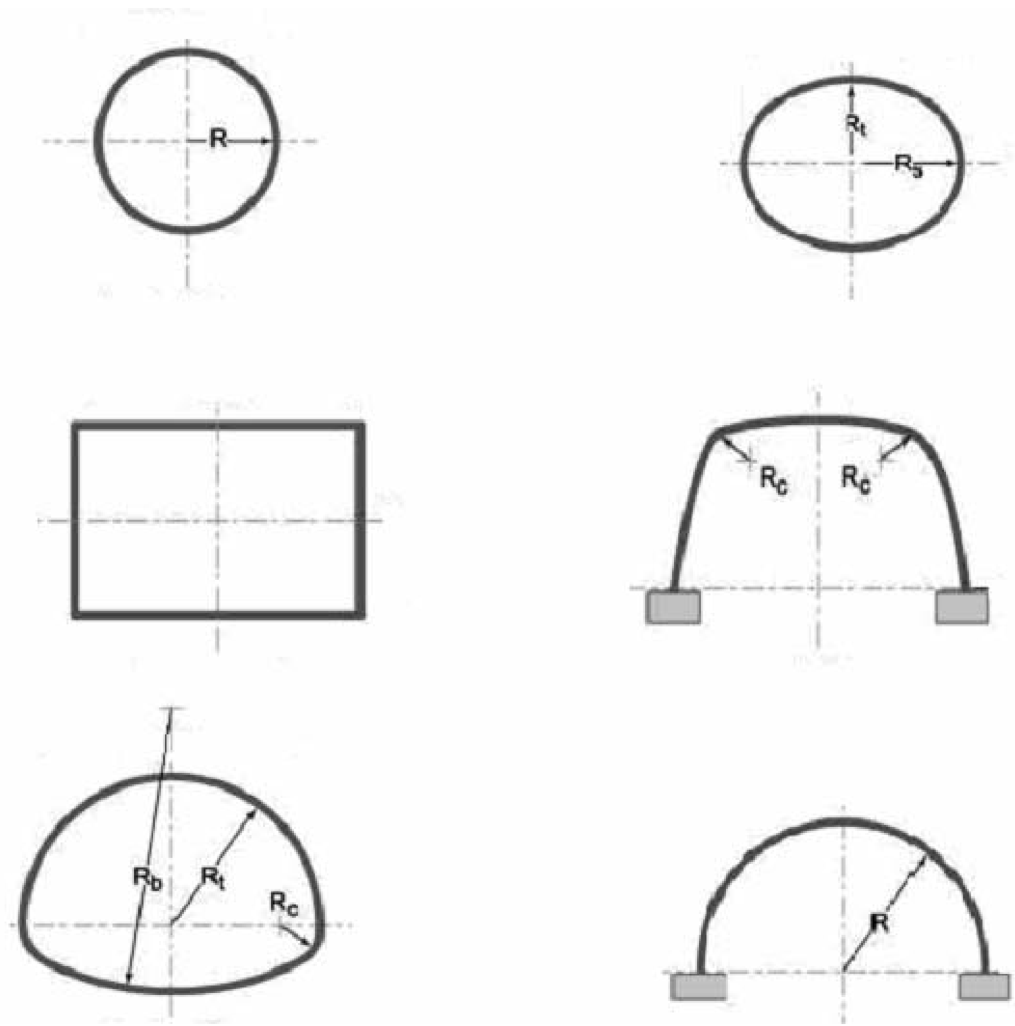


Figure A1.2: Geometric Dimensions of Culverts

Metal Pipes

28. Pitch:	29. Depth:	30. Gauge: *(thickness)*

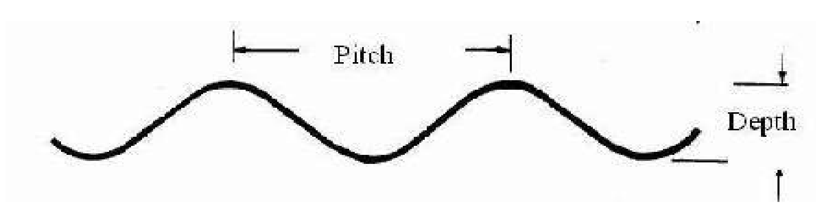


Figure A1.3: Pitch of Corrugated Metal Culverts

31. Maximum Height of Cover from Crown to Road Surface:

(See figure below)

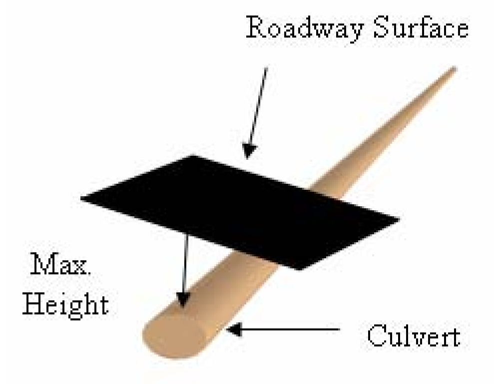


Figure A1.4: Maximum Height of Cover

A 1.3 ADDITIONAL INFORMATION

Type of End Treatment

32. Type:	33. Material:	34. Thickness:

Other

35. Slope of Embankment:	36. Skew Angle:
37. Roadway Material:	38. No. of Lanes:

A 1.4 HYDRAULIC INFORMATION

39. Streambed Material:	40. Drainage Area:
41. Design Peak Flow:	42. Manning's Coefficient 'n':

43. Design Discharge ‘Q’:	44. Design Headwater Depth:
45. Slope of the Culvert:	46. Bank Protection:
47. Type of Fish Passage:	48. pH of Water:

A 1.5 SAFETY ITEM

49. Type:	50. Material:	51. Span:

A 1.6 RENEWAL OR RENEWAL INFORMATION

52. Type of Renewal:	53. Date of Renewal:
54. Type of Renewal:	55. Date Rehabilitated:

APPENDIX -2
CULVERT INVENTORY MANUAL

A 2.1 CULVERT INVENTORY MANUAL

Item 1. Date of Inventory (8 digits)

Print the date of culvert inventory performed. The coding for date of inventory is as **MM/DD/YYYY**.

Ex: If the culvert inventory is performed on Jan 15th 2006, the coding will be:

01/15/06

Item 2. Name of the Person

Print the name of the person performing the culvert inventory as follows:
Last Name, First Name, Initial

Ex: Stevenson, Mark, P

Item 3. State Code (2 digits)

The state code is a national standard given by the Federal Information Processing (FIPS). The state codes are as follows:

Table A2.1: Inventory state codes

Code	**State**	**Code**	**State**
01	Alabama AL	15	Hawaii HI
02	Alaska AK	16	Idaho ID
03	NOT USED N/A	17	Illinois IL
04	Arizona AZ	18	Indiana IN
05	Arkansas AR	19	Iowa IA
06	California CA	20	Kansas KS
07	NOT USED N/A	21	Kentucky KY
08	Colorado CO	22	Louisiana LA
09	Connecticut CT	23	Maine ME
10	Delaware DE	24	Maryland MD
11	District of Columbia DC	25	Massachusetts MA
12	Florida FL	26	Michigan MI
13	Georgia GA	27	Minnesota MN
14	NOT USED N/A	28	Mississippi MS

29	Missouri MO	49	Utah UT
30	Montana MT	50	Vermont VT
31	Nebraska NE	51	Virginia VA
32	Nevada NV	52	NOT USED N/A
33	New Hampshire NH	53	Washington WA
34	New Jersey NJ	54	West Virginia WV
35	New Mexico NM	55	Wisconsin WI
36	New York NY	56	Wyoming WY
37	North Carolina NC	60	American Samoa AS
38	North Dakota ND	64	Fed States of Micronesia FM
39	Ohio OH	66	Guam GU
40	Oklahoma OK	68	Marshall Islands MH
41	Oregon OR	69	Northern Mariana MP Islands
42	Pennsylvania PA	70	Palau PW
43	NOT USED N/A	72	Puerto Rico PR
44	Rhode Island RH	78	Virgin Islands VI (US)
45	South Carolina SC		
46	South Dakota SD		
47	Tennessee TN		
48	Texas		

Ex: For Michigan, code – "**26**"

Item 4. County Code (3 digits)

The highway agency district in which the culvert is located shall be represented by a three-digit code given by the Federal Information Processing (FIPS) as follows:

Table A2.2: Inventory county codes for Michigan

Code	**County/District**	**Code**	**County/District**
001	Alcona	037	Isabella
002	Alger	038	Jackson
003	Allegan	039	Kalamazoo
004	Alpena	040	Kalkaska
005	Antrim	041	Kent
006	Arenac	042	Keweenaw
007	Baraga	043	Lake
008	Barry	044	Lapeer

009	Bay	045	Leelanau
010	Benzie	046	Lenawee
011	Berrien	047	Livingston
012	Branch	048	Luce
013	Calhoun	049	Mackinac
014	Cass	050	Macomb
015	Charlevoix	051	Manistee
016	Cheboygan	052	Marquette
017	Chippewa	053	Mason
018	Clare	054	Mecosta
019	Clinton	055	Menominee
020	Crawford	056	Midland
021	Delta	057	Missaukee
022	Dickinson	058	Monroe
023	Eaton	059	Montcalm
024	Emmet	060	Montmorency
025	Genesee	061	Muskegon
026	Gladwin	062	Newaygo
027	Gogebic	063	Oakland
028	Grand Traverse	064	Oceana
029	Gratio	065	Ogemaw
030	Hillsdale	066	Ontonagon
031	Houghton	067	Osceola
032	Huron	068	Oscoda
033	Ingham	069	Otsego
034	Ionia	070	Ottawa
035	Iosca	071	Presque Isle
036	Iron	072	Roscommon
073	Saginaw		
074	St Clair		
075	St Joseph		
076	Sanilac		
077	Schoolcraft		
078	Shiawassee		
079	Tuscola		
080	Van Buren		
081	Washtenaw		
082	Wayne		
083	Wexford		
084	Entire State		

Ex: If the culvert is located in Ingham County, then code “**033**”

Item 5. Place Code (3 digits)

The cities, township, villages and other census-designated places shall be identified using the Federal Information Processing Standards (FIPS) codes given in the current version of the census population and housing – geographic identification code scheme. If there is no FIPS place code, then code all zeros.

Item 6. Inventory Code (8 digits)

- **Route Signing Prefix (1 digit)** – Identify the route signing prefix for the inventory route using the following codes:

Code	Description
1	Interstate Highway
2	US Numbered Highway
3	State Highway
4	County Highway
5	City Street
6	Federal Lands Road
7	State Lands Road
8	Other

- **Classification (1 digit) –** Enter the designated classification of the above route as shown below:

Code	Description
1	Mainline
2	Alternative
3	Bypass
4	Spur
5	Business
6	Ramp or Connector
7	Service road or Unclassified
8	Other

- **Spur route is a short road forming a branch from a longer, more important route like freeway, interstate roadway or motorway**
- **Bypass or beltway is a road which always reconnects with the major road**
- **A business route is a branch from numbered highway which links the mainline of its parent route to the central business district of a city or town**

- **Route Number (5 - digit):** Code the route number of the inventory route in 5 digits. This value will be right justified with leading zeros filled in. Code 00000 for culverts on roads without numbers.

Ex:	Route Number	Code
	US127	00127
	I 96	00096
	I 90	00090

- **Directional Suffix (1 digit):** Code the directional suffix to the route number of the inventory route, which is a part of the route number using the following codes:

Code	Description
1	North
2	East
3	South
4	West
0	Not Applicable

Example of coding "Inventory Code" for a culvert located on Interstate 90 West
1st digit – Route signing prefix – Interstate – "1"
2nd digit – Level of service – Mainline – "1"
Next 5 digits – Route number – I 90 – "00090"
Last digit – Direction suffix – West – "4"

Therefore, Inventory Code is 11000904

Item 7. Functional Classification (2 digits)

Code the functional classification of the inventory route using the list below:

Code	Description
	Rural
01	Principal Arterial - Interstate
02	Principal Arterial - Other
03	Minor Arterial
04	Major Collector
05	Minor Collector
06	Local

Code	Description
	Urban
11	Principal Arterial - Interstate
12	Principal Arterial – Freeways or Expressways
13	Other Principal Arterial
14	Minor Arterial
15	Collector
16	Local

The culvert shall be located rural if not inside a designated urban area. The urban or rural designation shall be determined by the culvert location and not the character of the roadway.

Item 8. Mile Marker (7 digits)

Code the nearest mile marker number on the roadway to establish location of the culvert. It is a 7-digit code aligned to the assumed decimal point and zero filled wherever needed.

Ex:

Mile marker	***Code***
27.00	*0002700*
120.67	*0012067*

Item 9. Year Built (4 digits)

Print the year, the culvert was built as follows:

Ex: If the culvert is built in 1950, then print “**1950**”

Item 10. Latitude (11 digits)

xx degrees **xx** minutes **xx.xxxxx** seconds

Determine the latitude of each in degrees, minutes, and seconds. To get an accuracy of 3’ we have to consider 5 digits after the decimal point the leading zero can be added wherever necessary. The point of coordinate may be the invert of the culvert or any suitable point in the direction of inventory.

Ex:

Latitude	***Code***
81degrees 10 minutes 10.52132 seconds	**81101052132**

9 degrees 02 minutes 9.30213 seconds	**09020930213**

Item 11. Longitude (11 digits)

xx degrees **xx** minutes **xx.xxxxx** seconds

Determine the longitude of each in degrees, minutes and seconds to the nearest hundredth of a second. A leading zero must be coded wherever necessary. The point of coordinate may be the invert of the culvert or any suitable point in the direction of inventory.

Ex:

Longitude	***Code***
19 degrees 20 minutes 35.40453 seconds	**19203540453**
7 degrees 10 minutes 45.00 seconds 765	**07104500765**

Item 12. Maintenance Responsibility (2 digits)

This code shall represent the type of agency that has primary responsibility for maintaining the structure. If more than one agency has equal responsibility, then code one agency in the hierarchy of state, federal, county, city and other private.

Code	**Agency**
01	State Highway Agency
02	County Highway Agency
03	Town or Township Highway Agency
04	City or Municipal Highway Agency
05	Park, Forest, or Reservation Agency
06	Local Park, Forest, or Reservation Agency
07	Other State Agencies
09	Other Local Agencies
10	Private (other than railroad)
11	Railroad
12	State Toll Authority
13	Local Toll Authority
14	Other Federal Agencies (not listed below)
15	Bureau of Fish and Wildlife
16	U.S. Forest Service
17	National Park Service
18	Bureau of Land Management
19	Bureau of Reclamation
20	Corps of Engineers (Civil)
21	Corps of Engineers (Military)

22 Unknown/ others

Ex: If the Bureau of Fish and Wildlife is in charge of the culvert inventory, then code **“15”**

Item 13. Average Daily Traffic (ADT) (6 digits)

Code the average daily traffic volume (over the culvert) for the inventory route. The ADT coded should be most recent ADT counts available.

Ex:

ADT Volume	***Code***
350	**000350**
24, 300	**024300**

Item 14. Approach Roadway Width (4 digits)

Code the normal width of useable roadway approaching the structure. The code is the summation of all measurements as shown below:

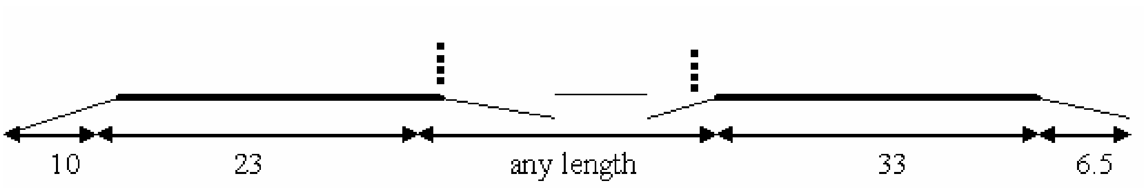


Figure A2.1: Roadway width

All measurements in feet

Ex:
Therefore, width of this road is 10 + 23 + 33 + 6.5 = 72.5 feet

Width	**Code**
72.5	0725
100.5	1005

Item 15. Culvert Marker (2 digits)

Code the culvert marker type present on or near the culvert structure.

Code	**Type**
01	Wood Post
02	Metal Post

03 Other type
00 No Marker
*Ex: If culvert marker type is wood, then code "**01**"*

Item 16. Barrel Shape (2 digits)

Code the shape of the culvert using the list below:

Code	**Type**
01	Circular
02	Pipe Arch
03	Horizontal Ellipse
04	Vertical Ellipse
05	Rectangular
06	Slab or 3 - sided
07	Arch

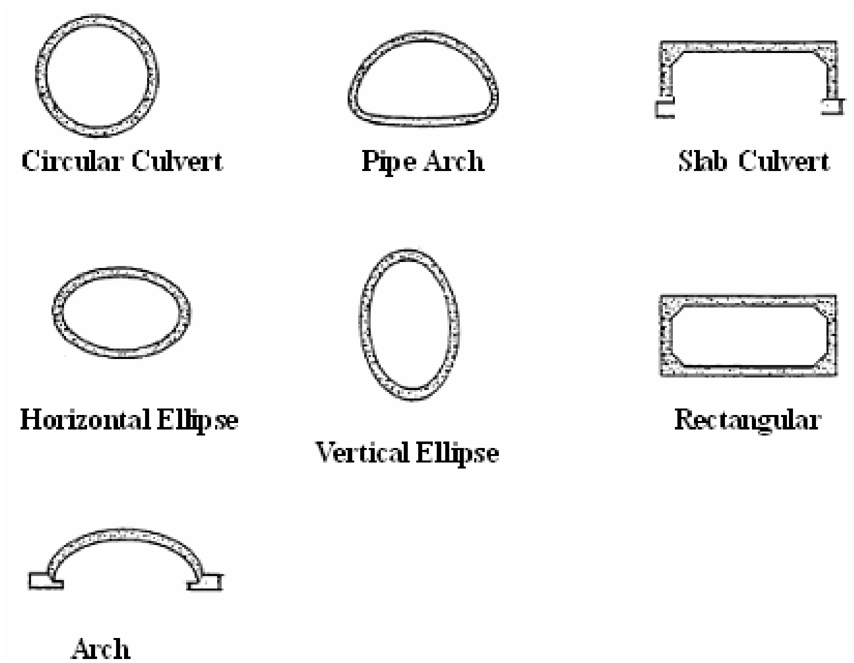


Figure A2.2: Different Shapes of Culverts
*If the culvert is circular, code "**01**"*

Item 17. Barrel Material (2 digits)

Following are the common culvert material types available:

Code	**Type**
11	Concrete

12	Corrugated Metal Pipe
13	Corrugated Steel Pipe
14	Corrugated Aluminum Pipe
15	Plastic Pipe
16	High Density Polyethylene
17	Polyvinyl Chloride
18	Vitrified Clay
19	Wood
20	Bituminous Fiber

Ex: If the culvert material is corrugated steel pipe, then code “**13**”

Item 18. Number of Cells (3 digits)

From the as-built culvert drawings, count the number of barrels and print as shown in the example. If, the number if not available, then code “000”

Ex: If the culvert has 10 barrels, code “**010**”

Note: Procedure to fill Items 19 to 31 is given on the Inventory Sheet

Item 32. Type of End Treatment: (2 digits)

Code the type of end treatment at the inverts:

Code	**Type**
10	Projecting
11	Mitered
12	Pipe End Section (Flared or Terminal)
13	Headwall
14	Wingwall
15	Headwall and Wingwall

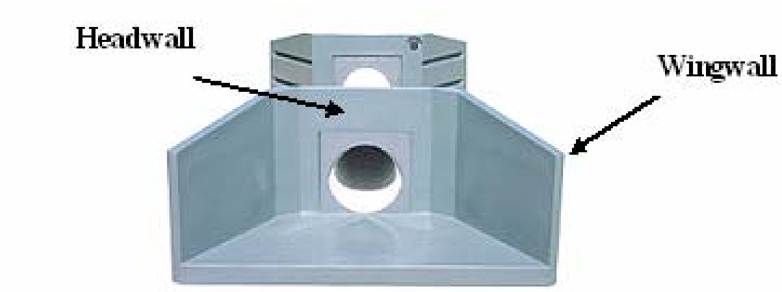


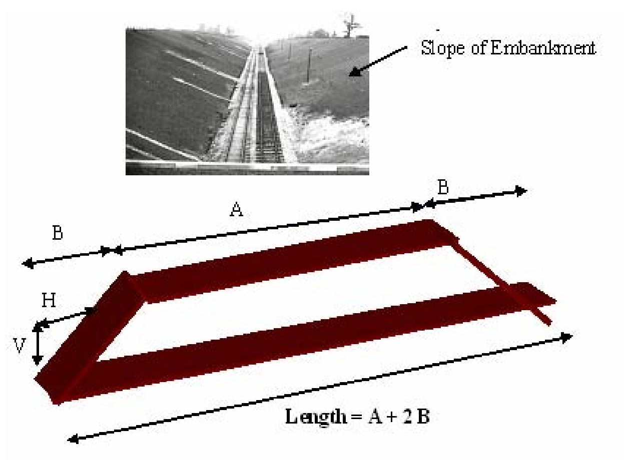
Figure A2.3: Types of end Treatments

Item 33 Material Refer to Item 17.

Item 34 Thickness Code the thickness of Culvert Barrel

Item 35 Slope of Embankment:

Slope of embankment is determined as follows:



Slope of Embankment = $\frac{H}{V}$

Figure A2.4: Slope of embankment

Item 36. Skew Angle (2 digits)

Stand at inlet, look across road perpendicular to road length and estimate degree of skew down slope.

Skew Angles

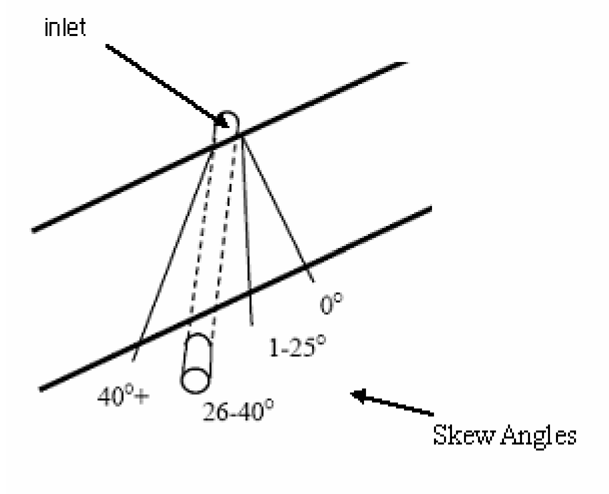


Figure A2.5: Slew Angle

Code	**Skew Angle (degrees)**
00	00
01	10 – 25
02	26 – 40
03	40 +

Item 37. Roadway Material (Alphabets)

The Federal Highway Administration (FHWA) roadway classification and respective codes are as follows:

Code	**Roadway Type**
A	Primitive Road
B	Unimproved Road
C	Graded and Drained Earth Road
E2	Gravel or Stone Road
F	Bituminous
G1	Mixed Bituminous - combined base with surface under 7”
G2	Mixed Bituminous - combined base with surface 7” or more
H1	Bituminous Penetration - combined base under 7”
H2	Bituminous Penetration - combined penetration 7” or more
Code	**Roadway Type**
I	Bituminous Concrete – sheet asphalt or rock asphalt road
J	Portland Cement Concrete Road
K	Brick Road
L	Block Road

Z	Water Macadam Road
Z1	Reinforced Concrete Road

Item 38. Number of Lanes (2 digits)

Code	Type
01	Single Lane
02	Double Lane
03	Four Lane
04	Six Lane
05	Eight Lane

Item 39. Stream Bed Material (Alphabets)

Code the type of stream bed material as follows:

Code	Type
C	Clay
S	Silt
K	Sand
G	Gravel
O	Other

Item 40. Drainage Area

Drainage area is an important factor in estimating the flood potential. The area of the watershed should be carefully defined by means of survey, photographic maps, U.S. geological Survey (USGS) topographic maps or a combination of these.

Maps are available at:
U.S. Geological Survey, Map Distribution,
Federal Center, Box 25286, Denver, CO 80225

Item 41. Design Peak Flow (2 digits)

Code the design peak flow of the culvert as follows:

Code	Design Peak Flow
01	10 Year Flood
02	20 Year Flood
03	50 Year Flood

04 100 Year Flood
05 Other

Item 42: Manning's Coefficient (n)

Manning's coefficient of roughness is used to estimate the capacity of a culvert to convey water. The "n" value is determined by inspecting the culvert and comparing them to the values given below:

Table A2.3: Manning's Coefficients

Type of Culvert	Roughness or Corrugation	Manning's "n"
Concrete pipe	Smooth	0.010 – 0.011
Concrete box	Smooth	0.012 – 0.015
Corrugated Metal Pipe (Arch and Box)	68 x 13 mm 2 2/3 x ½ in Annular	0.022 – 0.027
	68 x 13 mm 2 2/3 x ½ in Helical	0.011 – 0.023
	150 x 25 mm 6 x 1 in Helical	0.022 – 0.025
	125 x 25 mm 5 x 1 in	0.025 – 0.026
	75 x 25 mm 3 x 1 in	0.027 – 0.028
	150 x 50 mm 6 x 2 in Structural plate	0.033 – 0.035
	230 x 64 mm 9 x 2 ½ in Structural plate	0.033 – 0.037
Polyethylene (PE)	Smooth	0.009 – 0.015
	Corrugated	0.018 – 0.025
Polyvinyl Chloride (PVC)	Smooth	0.009 – 0.011

Note: For Item 43, 44 and 45 enter the design discharge (Q), design headwater depth and slope of the culvert from as-built drawings

Item 46. Bank Protection (3 digits)

Code the type of bank protection according to the list as follows:

Code	**Type**
010	Rip Rap
020	Loffelstein Block
021	Gabions
030	Earth Reinforcement System
040	Timber Retaining Walls
041	Steel Retaining Walls
050	Concrete Paving

Loffelstein blocks are a type of block retaining wall system. It is a caste concrete block with spoon like hollows.

Gabions are pre-assembled wire-mesh basket filled with rock. They are used for stabilizing slopes against movement and erosion.

Reinforcement of earth is the inclusion of resistant elements in a soil mass to improve its mechanical properties.

Concrete paving is paving the earth slopes with reinforced concrete

Rip Rap

Loffelstein Blocks

Concrete Paving of Earth Slopes

Figure A2.6: Types of Bank Protections

Item 47. Type of Fish Passage (3 digits)

Code the type of fish passage installed in the culvert according to the list below:

Code	**Type**
011	Baffle Wall
021	Fish Ladder
031	Resting Pools

Figure A2.7: Types of Fish Ladders

Item 48. pH of Water

Print the pH of the water in the inventory sheet.

Item 49. Safety Item

Code the safety structures accompanying the culvert as listed below:

Code	**Type**
10	Culvert Railings
20	Approach Guardrails

Figure A2.8: Safety Items for Culverts

Item 52 Type of Renewal (Alphabets)

Code the type of renewal according to the list below:

Code	**Type of Renewal**
ILR	In-Line Replacement
ThP	Thermoformed Pipe
SL	Sliplining
MSL	Modified Sliplining
PL	Panel Lining
CFP	Close-Fit Pipe
CIPP	Cured-In-Place Pipe

APPENDIX -3

CONDITION ASSESSMENT PROTOCOL

A 3.1 BASIC CONDITION ASSESSMENT

Basic condition assessment is performed to any culvert less than 10-foot diameter or opening irrespective of its shape or material.

A. General Information:

1. State Code:	2. County Code:	3. Place Code:
4. Culvert Identification Number:		5. Year Built:
6. Date of Inspection:	7. Inspector's Name:	
8. Maintenance Responsibility:		

B. Site Information:

9. Season:	10. Climate:
11. Time of Inspection:	12. Type of Stream:
13. Type of Inspection:	14. Water Level:
15. pH of Water:	16. Soil Resistivity:
17. Vegetation:	18. Natural Hazards:

C. Culvert Information:

19. Shape:	20. Material:
21. Number of Cells:	22. Type of End Treatment:

D. Condition Assessment:

a. Condition of Invert

b. Condition of End Treatment

c. Condition of Overall Culvert:

d. Condition of Roadway:

e. Condition of Embankment: [ ]

f. Condition of Footings: [ ]

E. Zone: (please tick one)

Satisfactory	
Monitored	
Critical	

F. Comments:	**G. Recommendations:**

A 3.2 ADVANCED CONDITION ASSESSMENT

METAL CULVERTS

A. Alignment	
B. Settlement	
C. Vegetation	
D. Seam	
E. Shape	
F. Corrosion	
G. Scouring	
Performance Score	

Comments:	**Recommendations:**

Performance score after repair or renewal of the culvert

% Performance Improvement

CONCRETE CULVERTS

A. Cracking

B. Scouring

C. Settlement

D. Joint Opening

E. Misalignment

F. Concrete Surface

Performance Score

Comments:	**Recommendations:**

Performance score after repair or renewal of the culvert

% Performance Improvement

PLASTIC CULVERTS

A. Misalignment

B. Shape

C. Seam

D. Settlement

E. Scouring

F. Split or Cracking

Performance Score

Comments:	**Recommendations:**

Performance score after repair or renewal of the culvert

% Performance Improvement

APPENDIX - 4

CONDITION ASSESSMENT MANUAL

A 4.1 GENERAL INFORMATION

Items 1 to 8 refer Inventory Manual

Item 9. Season (2 digits)

Code the season of the year, culvert condition assessment was performed. The list is as follows:

Code	Season
01	Spring
02	Summer
03	Fall
04	Winter

Item 10. Climate (2 digits)

Code the climate of the day, condition assessment was performed.

Code	Climate	
21	Very Hot	(Above 100 F)
22	Hot	(80 – 100 F)
23	Good	(65 – 79 F)
24	Fair	(40 – 64)
25	Cold	(32 – 40)
26	Freezing Cold	(Below 32)

Item 11. Time of Inspection

Code the time of culvert inspection

Item 12. Type of Stream (2 digits)

Code the type of stream entering into the culvert as follows:

Code	Type of Stream
10	Braided Stream
11	Straight Stream
12	Meandering Stream
13	Other
00	No Stream

Braided streams consists of multiple and interlacing channels. They are wide, and the banks are poorly defined and unstable.

Figure A4.1: Braided Stream

Straight streams are straight without branches and the ratio of the length of the thawing, or path of deepest flow, to the length of the valley proper is less than 1.5

Figure A4.2: Straight Stream

Meandering streams consists of alternating bends of an S-shape as shown in the figure.

Figure A4.3: Meandering Stream

Item 13. Type of Inspection (Alphabets)

Code the type of inspection procedure.

Code	Type of entry
P	Inspection from culvert ends
S	Manned entry inspection
V	CCTV inspection

Item 14. Water Level (2 digits)

Code the water level in the culvert:

Code	Water Level
05	Pressure flow
06	Half flow
07	Quarter flow
08	Small stream flowing
09	Ponding water
00	No water

Item 15. pH

Enter the pH value of the water in the inspection sheet

Item 16. Soil Resistivity:

Enter the soil resistivity in ohm-mm

Item 17. Vegetation

Code the vegetation in and around culvert as follows:

Code	Vegetation
51	No vegetation in and around culvert for at least 40 feet
52	Minor vegetation around culvert, but has no or less effect on culvert
53	Heavy vegetation in and around culvert
54	Culvert is completely covered by vegetation

Item 18. Natural Hazards

Determine the natural hazards on the culvert site.

Code	Type
AA	Animals in culvert site
KY	Poisonous plants
HU	Slippery Surfaces
MN	Posted Warnings
YO	No Danger

Figure A4.4: Animals in culverts


Figure A4.5: Slippery surface & Posted warning

A 4.2 BASIC CONDITION ASSESSMENT

Rating Scale:	**Score**
A – New or excellent condition	5
B – Good Condition	4
C – Fair condition	3
D – Poor Condition	2
E – Critical Condition	1

- Condition of the Inverts
- Condition of End Treatment
- Condition of the Roadway above Culvert
- Overall Condition of the Culvert
- Condition of the Embankment
- Condition of the Footing

Condition of the Invert

A – Looks new or in excellent condition

B – Age deterioration is minor, no deformations of the openings, no or less settlement of the debris, invert not corroded or eroded

C – Age deterioration is moderate, some deformations of the opening, minor cracks, and moderate settlement of debris, inverts corroded or eroded

D – Age deterioration is significant or failure of the inverts is imminent, inverts heavily corroded or eroded, large settlement of debris, major cracks

E – Ends totally/partially broken

Condition of End protection (headwall, wingwall, etc)

A – Looks new or in excellent condition

B – Good condition, light scaling, hairline cracking, no leakage, no spalling

C – Horizontal and diagonal cracking with or without efflorescence, minor rusting, leakage and erosion, minor scaling, differential or rotational settlement

D - Cracking with white efflorescence, major cracks, failure is imminent, heavily scaled or rusted, partial collapse of end protection

E – Total collapse of end protection

Overall condition of the culvert

A – Newly installed or lined culvert

B – Looks new with possible discoloration of the surface, galvanizing partially worn, hairline cracking, no settlement of the above roadway, light deformation, no debris inside the structure, light corrosion inside or outside the culvert

C – Medium rust or scale, pinholes throughout the pipe material, minor cracking, slight discoloration, isolated damages from cracking, minor settlement of the roadway, minor deformation of the culvert, minor settlement of debris inside the culvert

D – Heavy rust or scale, major cracks with spalling, exposed surface of the reinforcing steel, heavy settlement of the debris inside the structure, visible settlement of the above roadway, heavy deformation

E – Culvert is structurally or hydraulically incapable to function, exceeded its design life, culvert partially collapse or collapse is imminent

Condition of the roadway

A – Looks new and in excellent condition

B – Minor settlement of the roadway, no cracks

C – Minor settlement of the roadway and minor cracks

D – Heavy settlement of the roadway or major cracks

E – Roadway collapse is imminent

Condition of the Embankment

A – Soil in very good condition, no erosion found in and around the structure

B – Minor erosion away from the structure, no problem to the culvert

C – Moderate erosion near the structure, no cracks on the headwall

D – Slope stability problem near the culvert, extensive hairline cracks found near the headwall

E – Embankment has collapsed or failure is imminent

Condition of the Footings

A – Footing intact and in good condition

B – Moderate erosion and may cause cracking or settlement in the footing

C – Moderate cracking or differential settlement of the footing

D – Severe differential settlement has caused distortions in the culvert

E – Culvert has collapsed or failure is imminent

A 4.3 CALCULATION OF PERFORMANCE FACTOR

Rating system for performance calculation:

1 – Equal Importance
2 – Moderate Importance
3 – Intermediate Importance
4 – Strong Importance
5 – Extreme Importance

1. Performance calculation for component parts of culvert (Refer Table 8.9 on page 137)

2. Performance matrix of component parts of culvert (Refer Table 8.10 on page 137)

3. Relative weights are obtained from matrix in Table 8.10. and Table 8.11 on page 137 shows the respective relative weights.

Scale Range

5 4 3 2 1

← Upper Limit → Lower Limit

<u>Final Performance Score for categorizing the culverts into zones</u>

Performance Score	***Zone***	***Zone Meaning***
3.5 +	Satisfactory or Green	Safe
3.5 – 2.5	Monitored or Yellow	Intermediate Stage
> **2.5**	Critical or Red	Danger

A 4.4 ADVANCED CONDITION ASSESSMENT FOR CULVERTS IN CRITICAL ZONE

<u>Metal Culverts</u>

- Misalignment
- Settlement problems
- Vegetation
- Seam problems
- Shape
- Corrosion problems
- Scouring

Misalignment

A – No alignment problem found. The culvert is straight as designed

B – Minor misalignment problem at the joints. No Ponding of water

C – Minor misalignment problem – offset less than ½ in. and Ponding of water is less than or equal to 2 in.

D – Significant misalignment – offset more than ½ in. and less than 2 in. and Ponding of water is greater than 2 in. and less than 5 in.

E – Significant misalignment – offset greater than 2 in., Ponding of water greater than 5”

F – Culvert partially collapsed/collapse is imminent due to alignment problems

Seam problems

A – No seam problem, seams are tight or in excellent condition

B – Minor efflorescence or loss of galvanizing at seams, minor cracking at few boltholes

C – Minor cracking, evidence of backfill infiltration, minor rusting around bolts, more than 3 missing bolts in a row

D – Moderate cracking at boltholes, more than 6 bolts missing in a row, deflection caused by loss of backfill through open seams, major cracking at crown

E – Metal plate cracked from bolt to bolt on one side, significant backfill infiltration, crown open

F – Seams failed/failure is imminent

Settlement problems

A – No settlement of debris/culvert functioning as designed

B – Minor settlement of debris less than 5% of cross sectional area

C – Minor settlement of debris less than 10% of cross sectional area, vegetation growing inside the culvert

D – Settlement is more than 10% and less than 40% of cross sectional area, vegetation restricts the channel flow

E – Settlement more than 40% and less than 80%, occasional overtopping of the roadway

F – Culvert completely blocked causing water to pool, road closed due to channel failure

Vegetation/Debris

A – Very lighting floating debris or no debris

B – Light floating debris – small limbs or sticks, refuse, small plants growing

C – Medium floating debris (large sticks), large plants growing

D – Heavy floating debris (logs or trees) or heterogeneous fluid mass of clay, silt, sand, gravel, rock or refuse

E – Fairly uniform bed load of silt, sand, or gravel and less devoid of floating debris

F – Large boulders and large rock fragments carried as a bed load

Shape

A – New condition, smooth curvature in barrel

B – Top half of the pipe is smooth but minor flattening of the bottom, dimensions within 1% of the design.

C – Top half has smooth curvature but bottom half has flattened significantly, dimensions more than 1% and less than 15% of the design.

D – Significant distortions or deflections throughout the length of the pipe, dimensions between 10 – 15% of the design.

E – Structure partially collapsed with crown in reverse curve, extreme deflection/distortions, dimensions greater than 15% than designed.

F – Structure collapse/failure is imminent.

Corrosion/rusting

A – No corrosion looks new.

B – Superficial corrosion (less than 5% of the exposed area).

C – Moderate corrosion (more than 5% and less than 20% of the exposed area).

D – Significant corrosion (greater than 20% and less than 50% of the exposed area).

E – Heavy corrosion (greater than 50% of the exposed area).

F – Extensive perforations throughout the body of the culvert due to corrosion.

Scouring or Abrasion problem

A – No indication of scouring or bank erosion.

B – Mild indication of scouring or bank erosion (< 6 in.).

C – Moderate bed scour or bank erosion (6 in. – 2 ft).

D – Significant bed scours and bank erosion (> 2 ft).

E – Structure has been displaced or settled due to scouring or bank erosion.

F – Structure failed or failure is imminent due to bed scouring and bank erosion.

Check for localized damage like dents, bulges, creases, and tears. Document the type, extent and location of these defects in the comments box and recommend future repair action.

Table A4.1: ACA for Metal Culverts

	Alignment	Settlement	Vegetation	Seam	Shape	Corrosion	Scouring
Alignment	1	3	3	1	1	3	3
Settlement	0.333	1	3	1	1	1	1
Vegetation	0.333	0.333	1	1	1	1	1
Seam	1	1	1	1	1	3	3
Shape	1	1	1	1	1	3	3
Corrosion	0.333	1	1	0.333	0.333	1	4
Scouring	0.333	1	1	0.333	0.333	0.25	1

Table A4.2: ACA Matrix for Metal Culverts

	Alignment	Settlement	Vegetation	Seam	Shape	Corrosion	Scouring
Alignment	0.2300	0.3600	0.2720	0.1760	0.1760	0.2440	0.1875
Settlement	0.0768	0.1200	0.2720	0.1760	0.1760	0.0810	0.0625
Vegetation	0.0768	0.0399	0.0900	0.1760	0.1760	0.0810	0.0625
Seam	0.2300	0.1200	0.0900	0.1760	0.1760	0.2440	0.1875
Shape	0.2300	0.1200	0.0900	0.1760	0.1760	0.2440	0.1875
Corrosion	0.0768	0.1200	0.0900	0.0580	0.0580	0.0810	0.2500
Scouring	0.0768	0.1200	0.0900	0.0580	0.0580	0.0200	0.0625

Table A4.3: Relative Weights for Culvert after ACA

	Relative Weights
Alignment	0.2351
Settlement	0.1378
Vegetation	0.1378
Seam	0.1748
Shape	0.1748
Corrosion	0.1048
Scouring	0.0693

Concrete Culverts

- Cracking
- Scouring
- Settlement
- Joint Opening
- Alignment
- Concrete Surface

Cracking

A - New condition and looks excellent.

B - Minor hairline cracks on the surface of the culvert and on end treatments.

C - Extensive hairline cracks with/without minor delamination or spalling (depth less than 0.25 in.).

D – Major delamination or spalling exposing reinforcing steel (depth between 0.25 – 0.5 inches).

E – Extensive cracking, spalling and/or delamination (depth exceeding 0.5 inches).

F – Structure fully or partially collapse due to cracking.

Scouring

A – No scouring, looks new and in excellent condition.

B – Minor Scouring at the inlet, outlet and/or inside the culvert (depth < 6 in.).

C – Moderate scouring at the ends and/or inside the culvert (depth between 6 in. – 2 ft).

D – Significant scouring of the concrete bed (> 2 ft).

E – Reinforcing rods exposed due to extensive scouring.

F – Culvert collapsed/partially collapsed due to scouring.

Settlement

A – No settlement of debris or culvert functioning as designed.

B – Minor settlement of debris less than 5% of cross sectional area.

C – Minor settlement of debris less than 10% of cross sectional area, vegetation growing inside the culvert.

D – Settlement is more than 10% and less than 40% of cross sectional area, vegetation restricts the channel flow.

E – Settlement more than 40% and less than 80%, occasional overtopping of the roadway.

F – Culvert completely blocked causing water to pool, road closed due to channel failure.

Joint Opening

A – Joints are tight in excellent condition/ looks new.

B – Minor settlement at the joints, but in good condition.

C – Minor backfill infiltration due to joint opening.

D – Joint opening (less than 3 in.) and allowing backfill to infiltrate.

E – Significant infiltration or exfiltration due to joint opening (greater than 3 in.).

F – Culvert fully or partially collapsed due to joint opening.

Misalignment

A – Culvert is in excellent condition as designed, no misalignment.

B – Minor misalignment problem at the joints. No ponding of water.

C – Minor misalignment problem – offset less than ½ in. and ponding of water is less than or equal to 2 in.

D – Significant misalignment – offset more than ½ in. and less than 2 in. and ponding of water is greater than 2 in. and less than 5 in.

E – Significant misalignment – offset greater than 2 in. and Ponding of water greater than 5 in.
F – Culvert partially or fully collapsed due to misalignment of culvert.

Concrete Surface

A – Concrete surface looks new or in excellent condition.

B – Minor discoloration of the concrete surface; light scaling less than ¼ in., light honeycombing or efflorescence (less than 5% of the surface area).

C – Moderate discoloration; minor age deterioration; medium scaling (¼ in. – ½ in.) and/or honeycombing or efflorescence (5 – 15% of the surface area).

D – Age deterioration and discoloration is significant; major scaling (½ in. – 1 in.); major honeycombing or efflorescence (15 – 20%).

E – Age deterioration and discoloration is extensive; severe scaling (> 1”); severe honeycombing or efflorescence (greater than 20%).

F – Culvert is partially or fully failed; failure is imminent due to all or any of the above factors.

Table A4.4: Advanced Condition Assessment for Concrete Culvert

	Cracking	Scouring	Settlement	Joint Opening	Misalignment	Concrete Surface
Cracking	1	3	3	2	2	3
Scouring	0.333	1	1	1	1	3
Settlement	0.333	1	1	1	1	3
Joint Opening	0.5	1	1	1	1	3
Misalignment	0.5	1	1	1	1	3
Concrete Surface	0.333	0.333	0.333	0.333	0.333	1

Table A4.5: ACA Matrix for Concrete Culverts

	Cracking	Scouring	Settlement	Joint Opening	Misalign ment	Concrete Surface
Cracking	0.3334	0.4091	0.4091	0.3158	0.3158	0.1875
Scouring	0.1110	0.1364	0.1364	0.1579	0.1579	0.1875
Settlement	0.1110	0.1364	0.1364	0.1579	0.1579	0.1875
Joint Opening	0.1667	0.1364	0.1364	0.1579	0.1579	0.1875
Misalignment	0.1667	0.1364	0.1364	0.1579	0.1579	0.1875
Concrete Surface	0.1110	0.0454	0.0454	0.0526	0.0526	0.0625

Table A4.6: Relative Weight for Concrete Culvert after ACA

	Relative Weight
Cracking	0.3285
Scouring	0.1478
Settlement	0.1478
Joint Opening	0.1571
Misalignment	0.1571
Concrete Surface	0.0616

Plastic Culverts

Definitions:

Deflection – A deviation from the original design shape without the formation of sharp peaks or valleys

Buckling – A bend, wrap or crumbling. Types of buckling:

> *Hinging* – Yielding of the material due to excessive bending moment in the pipe wall
>
> *Wall crushing* – Yielding in the wall produced by excessive compressive stresses
>
> *Dimpling* – Used to describe a wavy or waffling pattern that occurs in the inner wall of the pipe due to instability

Split – A split is any separation in the wall material other than at the designed joint

Problems:

Misalignment
Shape – Deflection and Buckling
Seam problem
Settlement
Scouring
Split or cracking

Misalignment

A – Culvert looks new or as designed. No misalignment.

B – Minor misalignment problem at the joints. No ponding of water.

C – Minor misalignment problem – offset less than ½ in. and ponding of water is less than or equal to 2 in.

D – Significant misalignment – offset more than ½ in. and less than 2 in. and ponding of water is greater than 2 in. and less than 5 in.

E – Significant misalignment – offset greater than 2 in. and Ponding of water greater than 5 in.

F – Culvert partially or fully collapsed due to misalignment of culvert.

Shape

A – Culvert looks new or in excellent condition; Culvert wall smooth and as designed.

B – Culvert wall is smooth but deflection is less than 5% of the design; no buckling.

C – Deflection is between 5 – 10% of the design; minor dimpling thought the culvert pipe (< ½ in.).

D – Deflection between 10 – 20% of the design; moderate dimpling (½" - 1"); minor wall hinging or crushing in some locations.

E – Deflection greater than 20% but less than 40% of the design; severe dimpling (>1 in.); moderate or severe hinging or crushing throughout the culvert pipe.

F – Deflection greater than 40% of the design; culvert partially or fully collapsed due to severe dimpling or hinging.

Seam problem

A – Culvert looks new and in excellent condition.

B – Minor offset at the seam (< ½ in.) and possible infiltration.

C – Moderate offset at the seam (between ½ in. – 2 in.) and minor infiltration or exfiltration

D – Significant offset at the seam (between 2 in. – 4 in.) and moderate infiltration or exfiltration.

E – Severe offset at the seam (> 4 in.) and severe infiltration or exfiltration.

F – Seam open or culvert partially or fully collapsed due to seam opening.

Settlement

A – No settlement of debris or culvert functioning as designed.

B – Minor settlement of debris less than 5% of cross sectional area.

C – Minor settlement of debris less than 10% of cross sectional area, vegetation growing inside the culvert.

D – Settlement is more than 10% and less than 40% of cross sectional area, vegetation restricts the channel flow.

E – Settlement more than 40% and less than 80%, occasional overtopping of the roadway.

F – Culvert completely blocked causing water to pool, road closed due to channel failure.

Scouring

A – No evidence of scouring of culvert invert or ends.

B – Minor scour holes at some locations.

C – Moderate scour holes (< 1 in.) throughout the culvert material.

D – Significant scour holes (between 1 in. – 2 in.) or perforations at the invert.

E – Severe scour holes (>2 in.) or loss of significant invert material.

F – Culvert is partially or totally collapsed due to scouring.

Split/Cracking

A – Culvert in good condition as designed without any splits or cracking

B – Small splits (less than 3 in.; width less than ¼ in.) in few locations and/or hairline cracking

C – Minor splits (greater than 3 in. but less than 6 in.; width between ¼ in. – ½ in.) in few locations and minor cracking at crown or any location.

D – Major Splits (greater than 6 in.; width greater than ½ in.) and major cracking at crown or any location.

E – Splits wide open or crown failure.

F – Culvert partially or fully failure due to wide splits or severe cracking.

APPENDIX - 5

SURVEY QUESTIONNAIRE

SURVEY FORM

The Center for Underground Infrastructure Research and Education (CUIRE), Michigan State University and University of Cincinnati are collaborating on a major Midwest Regional University Transportation Center (MRUTC) project regarding the asset management of drainage infrastructure and culverts. The Primary objective of this project is to establish business rules and protocols for culvert inventory, inspection, renewal and maintenance of culverts *spanning less than 10'* (small culverts). The project also focuses on developing a platform for decision support system. This national survey is one of the most important tasks in achieving this objective since it will provide valuable information regarding the state of practice of culvert asset management throughout the nation. To show our appreciation for your time and efforts, we will send you a copy of the research findings upon completion.

There are 25 questions, and we estimate it will take an average of 15 minutes to complete. Your completion of this survey is completely voluntary. You are free to not answer any question or to stop participating at any time. As this is an electronic survey, we don't track or record the IP address from which you are responding. There are no risks or individual benefits (accept receiving a copy of the research findings as noted above) associated with taking this survey. The responses collected will be kept confidential by the researcher to the maximum extent allowable by law.

If you have any questions about this project, please contact Dr. Mohammad Najafi (najafi@msu.edu), Director, CUIRE, Michigan State University at (517)432-4937 or Dr. Sam Salem (osalem@uc.edu), Director, Infrastructure Systems and Management Program, University of Cincinnati at (513)556-3759. Also, if you have questions or concerns regarding your rights as a study participant, or are dissatisfied at any time with any aspect of this study, you may contact – anonymously, if you wish – Dr. Peter Vasilenko, PhD, Director of Human Research Protections, MSU, by phone: (517)355-2180, by fax: (517)432-4503, e-mail: irb@msu.edu or by regular mail: 202 Olds Hall, Michigan State University, East Lansing, MI 48824-1047. By completing this survey, you indicate your voluntary consent to participate in this study and have your own answers included in the project data set.

Table A6.1: Survey form table.

Personal Details:		
Respondent's Agency:		**Department of Transportation**
Respondent's Name:		
Title:		
Address:		
City:	**State:**	**Zip code:**
Phone Number:	**Fax Number:**	
E – mail Address:		

1. What is the definition of a culvert in your state?

2. What is the condition of the *majority* of culverts in your state?

- ❑ Very Good
- ❑ Good
- ❑ Poor
- ❑ Deteriorated

Very good – Looks new with possible discoloration of the surface, galvanizing partially worn, hairline cracking, isolated damage from cracking.

Good – Medium rust or scale, pinholes throughout the pipe material, minor cracking, slight discoloration, isolated damages from cracking.

Poor – Heavy rust or scale, major cracks with spalling, exposed surface of the reinforcing steel, invert eroded/corroded.

Deteriorated – Culvert is structurally or hydraulically incapable to function, exceeded its design life, culvert partially collapsed or collapse is imminent.

3. Does your DOT have a standard set of inventory guidelines for the following:

Culverts	**Drainage Infrastructure**
☐ Yes	☐ Yes
☐ No	☐ No
☐ Don't Know	☐ Don't Know

- *Inventory guidelines are business rules or protocols which indicate policy or procedure to list or track the current assets.*
- *Drainage Infrastructure includes manholes, catch basins, storm sewers, etc*

If "Yes" to above, please provide a link to access the associated files via Web or

attach a copy with this questionnaire.

4. Does your agency have a standard set of inspection guidelines for the following:

Culverts	**Drainage Infrastructure**
☐ Yes	☐ Yes
☐ No	☐ No
☐ Don't Know	☐ Don't Know

Inspection guidelines are business rules or protocols which indicate policy or procedure to inspect the current condition of the asset.

If "Yes" to above, please provide a link to access the associated files via Web or attach a copy with this questionnaire.

If yes to above, then continue with Question 5, otherwise go to question 8

5. Which of the following are included in the inspection guidelines?

Drainage Inlet: (Ex: catch basins)	☐ Yes	☐ No	
Channel: (Ex: open drains, ditches, etc)	☐ Yes	☐ No	
Manholes:	☐ Yes	☐ No	
Junction Box:	☐ Yes	☐ No	
Headwall:	☐ Yes	☐ No	
Endwall:	☐ Yes	☐ No	
Wingwall:	☐ Yes	☐ No	
Footing:	☐ Yes	☐ No	
Other:	☐ Yes	☐ No	**(Please Specify)**

6. What are the minimum and maximum sizes of inspected culverts in your state?

Metal: Minimum Size:____________ inches

Maximum Size:____________ inches

Concrete: Minimum Size:__________ inches

Maximum Size:__________ inches

CONTINUE QUESTION 6 …..

Plastic: Minimum Size:__________ inches

Maximum Size:__________ inches

Other: Minimum Size:__________ inches **(Please specify the type of material)**

Maximum Size:__________ inches

7. Which of the following factors are considered in the inspection guideline? Please rank the factors in order of their importance.

	Metal	Concrete	
Hydraulic Capacity:	☐ Yes ☐ No	☐ Yes ☐ No	Rank: ☐
Soil Conditions:	☐ Yes ☐ No	☐ Yes ☐ No	Rank: ☐
Joint Failures:	☐ Yes ☐ No	☐ Yes ☐ No	Rank: ☐
Corrosion:	☐ Yes ☐ No	☐ Yes ☐ No	Rank: ☐
Wall Thickness:	☐ Yes ☐ No	☐ Yes ☐ No	Rank: ☐
Deflection:	☐ Yes ☐ No	☐ Yes ☐ No	Rank: ☐
Cracking:	☐ Yes ☐ No	☐ Yes ☐ No	Rank: ☐

Others: **(please explain)**

Hydraulic Capacity includes:

- *Amount of sediments in the culvert*

- *Surface conditions of the pipe material*
- *Inlet and outlet conditions*
- *Change in flow conditions due to land development upstream*

8. Original hydraulic design of majority of culverts in your state is based on:

☐ 10 year flood

☐ 20 year flood

☐ 50 year flood

☐ 100 year flood

☐ Others: **(please explain)**

9. Does your DOT have a culvert dictionary?

☐ Yes

☐ No

☐ Don't Know

Culvert dictionary is a list of parameters which includes all the culvert elements to be inspected during inspection.

If "Yes" to above, please provide a link to access the associated files via Web or attach a copy with this questionnaire.

10. How often do you inspect culverts located on state highways and interstates?

☐ Less than 1 Year

☐ Every 1 – 2 years

☐ Every 2 – 5 years

☐ More than 5 years

- ☐ No specific frequency

11. Does your agency have an inspection *manual* for:

Culverts	**Drainage Infrastructure**
☐ Yes	☐ Yes
☐ No	☐ No
☐ Don't Know	☐ Don't Know

If "Yes" to above, please provide a link to access the associated files via Web or attach a copy with this questionnaire.

12. What factors are considered when *replacing or renewing* a culvert?

- ☐ Hydraulic problems
- ☐ Structural problems
- ☐ Deflection
- ☐ Material degradation
- ☐ Roadway Surface
- ☐ Inspection results
- ☐ Age of the culvert
- ☐ Other, **(please explain)**

13. Do you have any culvert *failure* cases reported?

☐ Yes

☐ No

☐ Don't Know

Failure is collapse of culvert due to deterioration.

14. Which division or who makes decisions regarding culvert repair, renewal or replacement projects or programs in your DOT?

- **Repair is reconstruction of short pipe lengths, but not the reconstruction of a whole pipeline. Therefore, a new design life is not provided.**
- **In culvert renewal, a new design life is provided to the existing pipeline system**
- **Replacement is when a new culvert is constructed to take place of the old culvert**

15. Is there a model or formula that your state uses in order to predict the life expectancy of culverts?

☐ Yes

☐ No

☐ Don't Know

If "Yes" to above, please provide a link to access the associated files via Web or attach a copy with this questionnaire

16. Explain briefly how you overcome confined space problems while inspecting culverts.

☐ CCTV

☐ Don't inspect inside, just inlet and outlet

☐ Others **(Please explain):**

17. What are the major structural or hydraulic culvert problems do you encounter in your culverts state wide?
18. What are the major *repair* methods do you use for aforementioned problems?

19. What are the major *renewal* methods you use for problems listed in question 17?

20. Does your DOT have a computer database inventory for:	
Culverts	**Drainage Infrastructure**
☐ Yes	☐ Yes
☐ No	☐ No
☐ Don't Know	☐ Don't Know

21. If "Yes" to the above question, what software is used?

Culvert: ____________________

Drainage Infrastructure: ____________________

22. Do you have a decision support system (DSS) for integrating culvert inventory, condition assessment and prediction of life cycle performance of a culvert?

- ☐ Yes
- ☐ No
- ☐ Don't Know

If "Yes" to above, please provide a link to access the associated files via Web or attach a copy with this questionnaire.

23. Do you have a DSS for selection of a specific method for renewal/ repair/ renewal of old and deteriorated culverts and drainage infrastructure?

- ☐ Yes
- ☐ No
- ☐ May be

If "Yes" to above, please provide a link to access the associated files via Web or attach a copy with this questionnaire.

24. Do you think study or improvement in culvert asset management is very necessary in your state?

☐ Yes ☐ No ☐ No comments

25. Additional questions or comments

APPENDIX - 6

SURVEY RAW DATA

Table A7.1: Definition of culvert by state.

Respondent Agency	Definition of Culverts in your state
Missouri	No Response
Georgia	No Response
Arkansas	A structure less than 20 feet of open span which carries water under or parallel to the road surface.
Iowa	Drainage structure with a span less than a bridge of 20 feet.
Louisiana	Any drainage structure under a roadway or other facility not defined as a bridge.
Illinois	We do not have an official definition.
Nevada	A structure used to convey off-site runoff through roadway embankment: Usually covered with embankment material and is composed of structural material around the entire perimeter.
Virginia	As defined in NHI course "Safety Inspection of In-Service Bridges" and FHA "Bridge Inspector's Training Manual"
Virginia	Drainage structure used on roads and driveways to carry stream flow, storm water runoff, or ditch flow. (This part of this survey is specifically for culverts with less than a 36 square foot opening)
North Carolina	A pipe that carries storm drainage.
Idaho	Anything with a span of less than 20 feet.
Ontario	A conduit usually covered by fill, whose primary function is to convey surface water through an embankment. There is also another definition based on the Canadian Bridge Design code which we also use which is "A structure the forms an opening through soil"
Alberta	A bridge size culvert is defined as a culvert that has a diameter of 1.5 m or larger. Non-round culverts having an equivalent flow area of at least a 1.5 m diameter round culvert are also consider bridge size culverts.
California	A conduit with a diameter or span less than 20 feet.
Alaska	No Response
North Dakota	No Response
Minnesota	No Response
Maryland	No Response
Quebec	A culvert is generally a small-scale engineering structure that is constructed underneath a roadbed, with an opening that is smaller than 3.0 m. It may be a conventional reinforced-concrete structure, or it may consist of a thin design that is built using reinforced concrete, corrugated metal, or

	thermoplastic.
New Hampshire	Currently we inspect ONLY single culverts 10' and greater OR multiple culverts that are greater than 10' combined length where the distance between them is less than half the radius of the pipes.
Florida	The Fl Specification Book defines as any structure not classified as a bridge that provides an opening under the roadway
Michigan	A structure that is usually designed hydraulically to convey surface runoff through an embankment. The span is less than 20 feet.
Pennsylvania	We do not have a formal definition, but it is a hydraulic structure that passes water flow under our highway system. Typical span range is 8-20 feet.
Nevada	No Response
Delaware	A culvert is a structure designed hydraulically to take advantage of submergence to increase hydraulic capacity.
Indiana	Drainage structures that have span(s) length of 20'-0 or less. They are grouped in two (2) categories: 'small culverts' less than 4'-0 span and 'large culverts' from 4'-0 through 20'-0. Answers to this questionnaire are in reference to the 'large culverts'
Ohio	Culvert: A 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 loads. For the purposes of this manual, a culvert will consist of all of the following even though they may support traffic loads directly: 1. Any structure with a span, diameter, or multi-cell structure with total span less than 10 feet when measured parallel to the centerline of the roadway. (This is known as the National Bridge Inventory span.) 2. Any structure that forms a passageway or conveys water through an embankment not inspected according to the definitions and terms of the Ohio Department of Transportation Bridge Inspection Manual.
Kansas	Pipes, Arch or Box Bridge Length > 20' We inspect "500 Series" between 10' and 20'
Oregon	Pipe, galvanized or steel.
Nova Scotia	A single structure with a span less than 3 meters.
Tennessee	A structure that is less than 20 feet in length. Structures 20 feet and over are classified as a bridge.
Washington State	A culvert is a conduit under a roadway or embankment used to maintain flow from a natural channel or drainage ditch

Table A7.2: Number for each state.

No	State/Province
1	Missouri
2	Georgia
3	Arkansas
4	Iowa
5	Louisiana
6	Illinois
7	Nevada
8	Virginia
9	Virginia
10	North Carolina
11	Idaho
12	X
13	Ontario
14	Alberta
15	California
16	Alaska
17	XXX
18	North Dakota
19	Minnesota
20	Maryland
21	Quebec
22	New Hampshire
23	Florida
24	Michigan
25	Pennsylvania
26	Nevada
27	Delaware
28	Indiana
29	Ohio
30	Kansas
31	Oregon
32	Nova Scotia
33	Tennessee
34	Washington

Table A7.3: Questionnaire Answers for each state.

No	Q1:				Q2:
	Very Good	Good	Poor	Deteriorated	
1	0	1	0	0	
2	0	0	0	0	
3	1	0	0	0	No
4	0	1	0	0	Yes
5	0	1	0	0	No
6	0	1	0	0	Yes
7	0	1	0	0	No
8	0	1	0	0	Yes
9	0	1	0	0	Develop Ph
10	0	1	1	0	Yes
11	0	0	0	0	Yes
12	0	0	0	0	
13	0	1	0	0	Develop Ph
14	0	1	0	0	Yes
15	0	1	0	0	Yes
16	0	1	1	0	Yes
17	0	0	0	0	
18	0	1	0	0	No
19	0	1	0	0	Yes
20	0	1	0	0	Yes
21	1	0	0	0	Yes
22	0	0	1	0	No
23	0	1	0	0	Yes
24	0	0	0	0	
25	0	1	0	0	Yes
26	0	1	0	0	Yes
27	0	1	0	0	Yes
28	0	1	1	0	Develop Ph
29	0	1	0	0	Yes
30					
31	0	1	0	0	No
32	0	1	0	0	No
33	0	1	0	0	Yes
34	0	1	0	0	Develop Ph

No:	Q 4:	Q5:	Q6:	Q7:
1				
2				
3	50 year	Development Phase	Yes	Every 2-5 years
4	50 year	No	Yes	Every 1-2 years
5	100 year	No	Yes	Every 2-5 years
6	20 year	Development Phase	No	Every 2-5 years
7		No	Yes	No Specific Freq
8	100 year	Yes	No	Every 2-5 years
9	Other	Yes	Yes	No Specific Freq
10	50 year			
11	20 year	No	Yes	Every 2-5 years
12				
13	Other	Yes	Yes	Less than 1 year
14	100 year	Yes	Yes	Every 2-5 years
15	50 year	Yes	Yes	Every 2-5 years
16	100 year	No	Yes	Every 2-5 years
17				
18	20 year	No	Yes	No Specific Freq
19	50 year	Yes	Not Recorded	No Specific Freq
20	100 year	Yes	No	Every 2-5 years
21	10 year	Yes	Yes	Every 2-5 years
22		No	No	Every 1-2 years
23				
24				
25	50 year	Yes	Yes	Every 2-5 years
26				
27	Other	Yes	No	Every 2-5 years
28	100 year	Development Phase	Yes	Every 1-2 years
29	Other	Yes	Yes	Every 2-5 years
30				
31		No	Yes	Less than 1 year
32	50 year	No	Yes	Every 1-2 years
33				
34		Development Phase	Yes	No Specific Freq

No:	Q 8:	Q9:								
		Dr. Inl	Cha nnel	Man hole	Junc	Head	End	Wing	Foot	Oth
1										
2										
3	No									
4	Yes	Yes	Yes			Yes	Yes	Yes	Yes	
5	No									
6	Yes		Yes			Yes	Yes	Yes	Yes	
7	No									
8	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
9	Yes		Yes			Yes	Yes	Yes		
10	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes	
11	Yes					Yes	Yes	Yes	Yes	
12	Yes					Yes	Yes	Yes	Yes	
13	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
14	Yes		Yes			Yes	Yes	Yes	Yes	
15	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
16	No									
17										
18	Yes	Yes	Yes			Yes	Yes	Yes	Yes	
19		Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes
20	Yes		Yes		Yes	Yes	Yes	Yes	Yes	
21	Yes	Yes	Yes			Yes	Yes	Yes	Yes	Yes
22	No									
23	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
24										
25	Yes	Yes	Yes			Yes	Yes	Yes	Yes	
26										
27			Yes			Yes	Yes	Yes	Yes	
28	Yes					Yes	Yes	Yes	Yes	Yes
29	Yes	Yes	Yes			Yes	Yes	Yes	Yes	
30										
31	No									
32	No									
33										
34	Dev. Ph	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes

No.	Q10.	Q11.						
		Metal Culverts						
		Hyd	Soil	Joint	Corr	Wall	Def	Crack
1								
2								
3	No							
4	No	No	No	Yes	Yes	No	Yes	Yes
5	No							
6	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7	No							
8	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
9	Yes	Yes	No	Yes	Yes	No	Yes	No
10		Yes	Yes	Yes	Yes	Yes	Yes	Yes
11	No	No	No	Yes	Yes	No	Yes	Yes
12								
13	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
14	Yes	Yes	Yes		Yes	Yes	Yes	
15	Yes	Yes	No	Yes	Yes	No	Yes	Yes
16	No	Yes	No	Yes	Yes	No	Yes	Yes
17								
18	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
19	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
20	Yes	Yes	No	Yes	Yes	Yes	Yes	No
21	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
22	Yes							
23								
24								
25	Yes	Yes	No	Yes	Yes	No	Yes	No
26								
27	No	No	Yes	Yes	Yes	No	Yes	No
28	Dev. Ph	Yes	Yes	Yes	Yes	Yes	Yes	Yes
29	Yes	Yes	No	Yes	Yes	No	Yes	Yes
30								
31	No							
32	No							
33								
34	Dev. Ph	No	Yes	Yes	Yes	Yes	Yes	Yes

No.	Q11. cont						
	Concrete Culverts						
	Hyd	Soil	Joint	Corr	Wall	Def	Crack
1							
2							
3							
4	No	No	Yes	Yes	No	Yes	Yes
5							
6	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7							
8	Yes	Yes	Yes	Yes	Yes	Yes	Yes
9	Yes	No	Yes	No		Yes	Yes
10	Yes	Yes	Yes	Yes	Yes	Yes	Yes
11	No	No	Yes	Yes	No	Yes	Yes
12							
13	Yes	Yes	Yes	Yes	No	Yes	Yes
14	Yes	Yes	Yes	Yes	Yes	Yes	Yes
15	Yes	No	Yes	Yes	No	Yes	Yes
16	Yes	No	Yes	No	No	Yes	Yes
17							
18	Yes	Yes	Yes	Yes	Yes	Yes	Yes
19	Yes	Yes	Yes	Yes	Yes	Yes	Yes
20	Yes	No	Yes	Yes	Yes	No	Yes
21	Yes	Yes	Yes	Yes	Yes	No	Yes
22							
23							
24							
25	Yes	No	No	Yes	No	No	Yes
26							
27	No	Yes	Yes	No	No	Yes	Yes
28	Yes	Yes	Yes	No	No	No	Yes
29	Yes		Yes	Yes	No		Yes
30							
31							
32							
33							
34	No	Yes	Yes	Yes	Yes	Yes	yes

No.	Q12.							
	Hyd	Struct	Def	Mat	Road	Insp	Age	Other
1								
2								
3	Yes	Yes	Yes	Yes	No	Yes	Yes	No
4	Yes	Yes	Yes	No	No	Yes	Yes	No
5	Yes	Yes	No	Yes	No	No	No	No
6	Yes	Yes	Yes	Yes	No	Yes	Yes	No
7	Yes	Yes	Yes	Yes	Yes	Yes	No	No
8	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
9	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
10								
11	Yes	Yes	Yes	No	No	Yes	No	No
12								
13	Yes	Yes	No	Yes	Yes	Yes	No	No
14	Yes	Yes	Yes	Yes	No	Yes	Yes	No
15	No	Yes	No	Yes	No	No	No	No
16	Yes	Yes	Yes	Yes	No	Yes	No	No
17	No	No	No	No	No	No	No	No
18	Yes	Yes	Yes	No	Yes	No	Yes	No
19	No	Yes	Yes	Yes	Yes	Yes	Yes	No
20	Yes	Yes	No	Yes	Yes	No	No	No
21	Yes	Yes	Yes	Yes	Yes	Yes	No	No
22	Yes	Yes	No	No	No	No	No	No
23								
24								
25	Yes	Yes	Yes	Yes	Yes	No	No	No
26	No	No	No	No	No	No	No	No
27	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
28	Yes	Yes	Yes	No	No	Yes	No	No
29	Yes	Yes	Yes	No	No	Yes	No	No
30								
31	No	No	No	Yes	No	No	No	No
32	Yes	Yes	No	Yes	Yes	No	No	No
33	No	No	No	No	No	No	No	No
34	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No

No.	Q13.	Q14.	Q15.
1			
2			
3	No		CCTV
4	No		Others
5	No	Other	Don’t inspect inside, just inlet and outlet
6	No		Others
7	Dev. Ph.		CCTV
8	No		CCTV
9	Dev. Ph.	Other	Don’t inspect inside, just inlet and outlet
10			
11	No		Others
12			
13	No	Yes	Don’t inspect inside, just inlet and outlet
14	Dev. Ph.	Yes	Others
15	No		CCTV
16	No		Don’t inspect inside, just inlet and outlet
17			
18	No	No	Don’t inspect inside, just inlet and outlet
19	No	Other	CCTV
20	Yes	Yes	Others
21	No	Yes	Others
22			
23			
24			
25	No		Don’t inspect inside, just inlet and outlet
26			
27	Yes	Yes	Others
28	No	Yes	Others
29	No		Others
30			
31	No		Don’t inspect inside, just inlet and outlet
32	No		Don’t inspect inside, just inlet and outlet
33			
34	No		CCTV

No.	Q17.				
	Point Source	Internal Seal	Grouting	Robotic Repair	Other
1					
2					
3	No	Yes	Yes	No	No
4	Yes	Yes	Yes	No	No
5	Yes	No	No	No	No
6	Yes	No	No	No	No
7	No	Yes	Yes	No	No
8	Yes	Yes	Yes	No	No
9	No	No	No	No	No
10					
11	No	No	No	No	Yes
12					
13	Yes	Yes	Yes	No	No
14	No	No	No	No	Yes
15	No	No	Yes	No	No
16	Yes	No	No	No	Yes
17	No	No	No	No	No
18	No	No	No	No	No
19	No	No	No	No	No
20	No	No	Yes	No	No
21	No	No	No	No	Yes
22	No	No	No	No	No
23					
24					
25	Yes	No	Yes	No	No
26	No	No	No	No	No
27	No	No	No	No	Yes
28	No	No	No	No	Yes
29	No	No	No	No	No
30					
31	Yes	No	No	No	No
32	Yes	No	No	No	No
33	No	No	No	No	No
34	No	No	No	No	Yes

No.	Q 18.			
	Cured In Place Pipe	Sliplining	Pipe Bursting	Other
1				
2				
3	No	Yes	No	No
4	No	No	No	No
5	No	No	No	Yes
6	No	No	No	No
7	No	Yes	No	No
8	No	Yes	No	No
9	No	No	No	No
10				
11	No	No	No	Yes
12				
13	No	Yes	Yes	No
14	No	No	No	Yes
15	No	Yes	No	No
16	No	No	No	No
17	No	No	No	No
18	No	No	No	No
19	Yes	Yes	No	No
20	Yes	No	No	No
21	No	Yes	No	No
22	No	No	No	No
23				
24				
25	No	Yes	No	No
26	No	No	No	No
27	No	No	No	No
28	No	Yes	No	No
29	No	No	No	No
30				
31	No	Yes	No	No
32	Yes	No	No	No
33	No	Yes	No	No
34	No	No	No	Yes

	Q 19.	Q 20.	Q 21.	Q 22.
1				
2				
3	No		No	No
4	No		No	Dev. Ph.
5	No		No	No
6	Dev. Ph.		No	No
7	No		No	No
8	Yes	HTRIS, PONTIS/ORACLE	No	Yes
9	Dev. Ph.	Asset Management System	Dev. Ph.	Dev. Ph.
10				
11	Yes	PONTIS	No	No
12				
13	Yes	OBMS in VB> 3m	No	No
14	Yes	In House	Yes	Yes
15	Yes	MS Access	No	No
16	Dev. Ph.	In House	No	No
17				
18				
19	Yes	Oracle	No	No
20	Yes		Yes	Yes
21	Yes	Oracle	No	No
22				
23				
24				
25			No	
26				
27	Yes	PONTIS	Yes	Yes
28	Yes	In House Access Database	No	No
29	Yes	In House Software	No	No
30				
31	No		No	No
32	No		No	No
33			No	
34	Dev. Ph.		No	Dev. Ph.

	Q 23.
1	
2	
3	5
4	4
5	3
6	7
7	9
8	9
9	6
10	
11	3
12	
13	7
14	7
15	9
16	5
17	
18	
19	6
20	8
21	7
22	
23	
24	
25	5
26	
27	9
28	7
29	7
30	
31	4
32	4
33	7
34	5

APPENDIX 7 - FORMS CR87 AND CR86

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 A7.1: Ohio DOT Culvert Inventory Report

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:

INSPECTED BY:________________DATE:___________ REVIEWED BY:______________________ DATE:_______.

Figure A7.2: Ohio DOT Culvert Inspection Report

APPENDIX 8 - CULVERT REPAIR PROCEDURES

A 8.1 DETAILS OF THE REPAIR PROCEDURES

FHWA Culvert Repair Practices Volume 2 provides the repair practices for Concrete and Steel culverts in detail. This section presents a summary of these procedures.

A 8.2 REPAIRING CRACKS IN CONCRETE

Depending on the type and cause of the cracks either a flexible or a rigid material should be used. Procedure for a Flexible Sealant is as follows:

1- The surface of the concrete should be cleaned.
2- A groove should be routed into the surface of the crack.
3- Dust and debris should be cleaned out of the crack.
4- The crack should be filled in with the sealant by pressure injection or troweling.
5- The surface should be smoothened by removing the excess sealant.

Procedure for installation of a Portland Cement Mortar or Grout includes:

1- The surface of the concrete should be cleaned.
2- Built-up seats and grout nipples should be installed at intervals along and astride the crack.
3- The crack between the grout nipples should be sealed by using cement paint, sealant, or grout.
4- The crack should be flushed for cleaning and testing the seal.
5- The crack should be grouted.

A 8.3 PATCHING

For this method, the following procedure should be followed:

1- The exact boundaries of the distressed concrete should be determined. This may be achieved by tapping with a hammer or a steel rod.
2- Delaminated and/or broken concrete should be removed.
3- All dust and debris should be removed by air or sand blasting.
4- A cement or cement-latex grout should be applied to the sides and bottom of the area.
5- The patching material should be placed in the repair area.
6- The patch area should be cured without disturbance by using wet burlap or a moisture barrier.

A 8.4 SEALING CULVERT JOINTS BY USING STEEL EXPANSION RING GASKETS

For this method, the following procedure should be followed:

1- The type and width of the band should be determined depending on the amount of separation and misalignment.
2- A gasket should be determined depending on the selected band.
3- Bands should be fabricated using two sections which will conform to the existing pipe shape.
4- The repair area where the band is going to be placed should be cleaned and prepared.
5- The band should be installed with the gasket either with the two sections bolted together or as single units.
6- A tight fit should be realized by tightening the bolts evenly.
7- The edges of the band should be sealed by using a mastic sealant.

A 8.5 REPAIRING AND STRENGTHENING THE CROWN OF CULVERTS

The following procedure should be employed if the depth of cover is shallow and the amount of distress is not excessive.

1- The backfill material above and around the upper portion of the culvert should be removed.
2- The existing culvert should be repaired by removing the damaged portion and replacing it with a similar material (if it is a metal culvert) or with a cast-in place concrete (if it is a concrete culvert).
3- Shear studs (for metal culverts) or bolts (for concrete culverts) should be installed to ensure the composite reaction.
4- Reinforcing steel should be installed above the culvert.
5- Cast-in place concrete should be installed and finished around the upper portion of the culvert.
6- The backfill material should be put back in place with proper compaction.

A 8.6 UNDERPINNING

For this method, the following procedure should be followed:

1- A sandbag cofferdam should be constructed or the stream should be diverted by using temporary pipes.

2- All exposed concrete should be cleaned of marine growth and loose or deteriorated concrete should be removed.
3- A depth of two feet below the scour hole should be excavated.
4- Dowel holes should be drilled. Dowels should be set and installed. Additional reinforcing and anchor forms should be set.
5- Concrete should be placed and consolidated. Scour area should be completely filled.
6- Forms should be removed and gabions or stone riprap should be used to protect against continued stream bed erosion.

A 8.7 INVERT PAVING

For this method, the following procedure should be followed:

1- Water should be diverted prior to and during the placement of pavement.
2- For round pipes bottom 25 percent of the inside circumference should be paved, for pipe arches 30 – 35 percent of the inside circumferences should be paved.
3- The minimum coverage should be 4 inches over the corrugations.
4- The pavement should be reinforced with steel fabric reinforcement.
5- The pavement should have a smooth finished surface.
6- The pavement should be cured for 48 hours before water is allowed into the culvert.

A 8.8 REROUNDING / RESHAPING METAL CULVERTS

Depending on the cover of depth there are two different procedures for rerounding metal culverts. For shallow culverts, backfill above the culvert should be removed, the deformed portions of the culvert should be rerounded from inside by using hydraulic jacks and the backfill should be replaced. For culvert under a high cover depth, the distorted section should be removed by using a cutting torch, the backfill material behind the cut section should be removed, a new or reshaped section should be welded instead of the cut portion and the voids behind the newly installed portion should be grouted.

A 8.9 REPAIRING CORRUGATED METAL STRUCTURAL PLATE SEAMS BY USING REINFORCING BARS

For this method, the following procedure should be followed:

1- The length of the splice should be determined.
2- The repair area should be cleaned.

3- Plain #5 reinforcing should be placed where a good contact is established on each side of the joint.
4- The bar should be tack welded to both plates.

A 8.10 TEMPORARY BRACING OF CULVERTS

Temporary bracing is used when a culvert is extremely distorted and a sudden collapse is expected. This sudden collapse is avoided by installing temporary braces usually made out of timber. The disadvantage of temporary bracing is the disruption of flow though the culvert. The procedure consists of installing vertical braces between the crown and the invert of the culvert. Point loads at the ends of the braces should be avoided by using timber sills. The butt joints of the top and bottom of sills should be staggered.

APPENDIX 9 – CULVERT INSPECTION TECHNOLOGIES

A 9.1 INTRODUCTION

Culverts and other drainage structures should be inspected within regular intervals in order to avoid failures problems. Various techniques have been developed for pipe inspection and they can also be used for culvert and drainage structure inspection. Depending on the size of the culvert it may be possible for the inspector to enter and perform the inspection but in this case the inspection data cannot be kept for the record. Moreover, this situation may pose safety risks for the inspector. Following techniques and equipment can be used whenever the size of the culvert does not allow the inspector to enter the culvert or when it is not safe to perform man-entry inspections. Refer to Najafi (2005) for a complete description of pipeline inspection technologies.

A 9.2 CCTV INSPECTION

The Closed Circuit Television (CCTV) is the most widely used inspection technique for sewer inspection (Figure A9.1). The CCTV uses a television camera together with video monitor, videocassette recorders, and recording devices. CCTV uses a camera mounted on a robot that enters the culvert or drainage system. The camera generally looks forward as the robot system moves along the culvert axis. This allows the operator to examine and evaluate the entire length. Some of the CCTVs have pan and tilt, and zoom cameras attachments to the robot, which can find defects hidden from a forward looking camera behind connections and other obstructions within the culvert. Sonar or ultrasound systems are often attached to the robots which can examine the portions of the culvert below the waterline. If the CCTV equipment is attached with a light line attachment to assist, it can figure out smaller deformations in the culverts. The faults and defects identified through CCTV inspections might include longitudinal and circumferential cracks, collapsed sections, displaced bricks, broken pipes, defective and displaced joints, evidence of abrasion or corrosion, siltation, encrustation, root penetration, loss of mortar, deformation and infiltration.

A key factor for the success of a CCTV inspection is establishing proper reference points so the video can be tied to exact locations in the pipe being inspected. In addition, especially when videotape is used for analysis, the results are highly dependent on the quality of the equipment, their degree of maintenance, and timeliness of hardware and software updates. The main advantage of CCTV is that, this method provides permanent visual records which can be used later and it is very easy to use.

Along with the advantages it also has some disadvantages such as, it is useful only when the flow is less, the CCTV inspection may miss certain type of defects especially those that are hidden from the camera by obstruction as it looks down the culvert, slight deformations of the culvert may go unnoticed and any defect hidden beneath the water inside the sewer will definitely not be found and the quality of data is dependent on the skills of the operator.

Figure A9.1: CCTV Camera in a Partially Flowing Culvert

A 9.3 SSET – SEWER SCANNING EVALUATION TECHNOLOGY

The SSET was developed as an advanced and innovative pipeline condition assessment technology. SSET was developed to overcome the limitations of CCTV pipeline inspection systems. SSET captures three streams of digital data without the need to stop the forward motions of the SSET probe within the culvert. These data are Forward View (FV), Side Scan (SS) and Position Data (PD).

The Forward View is the same view as it is produced in the CCTV system. The Side is very special as it permits in real time to open up the pipe and lay it out flat. This unique feature permits looking into 100% of the wall at the same angle and light intensity that minimizes operator error resulting from image skewness light reflections, and shadowing. When the FV and SS are combined, it provided a three dimensional perspective. PD permits real time mapping of the probe as it moves through the pipe by using an integrated inclinometer and gyroscopic network.

The SSET process consists of the field data acquisition (FDA) phase and the data analysis and interpretation (DAI) phase. The SSET FDA process allows the operator to capture complete and accurate structure condition assessment information automatically without requiring the operator to stop code and classify defects and features in the field. Taking this responsibility away from the field technicians, allows them to stay focused on what they are best qualified to do, which is to make sure that the equipment is being operated properly and the project is being managed safely. The DAI phase allows analysis to use advanced SSET analysis software to conduct a thorough and accurate DAI report.

A 9.4 LASER BASED SCANNING SYSTEMS

Laser based scanning systems can be used to evaluate both the shapes and the types of defects the culvert contains (Figure A9.2). These systems are restricted to the part of the sewer above the waterline, but they can make more accurate inspections of sewer condition. An additional advantage of this technique is that the information from the laser scans is readily recorded and analyzed by computer, substantially reducing operator errors. This method is more effective because finer defects can be detected and the results of an examination and operator fatigue, which can lead to most defects in a CCTV assessment, are reduced.

Figure A9.2: Laser-Based Scanning Systems

A 9.5 SONAR – ULTRASONIC INSPECTION

Ultrasonic inspection is performed using a beam of very high frequency coherent sound energy, with the frequency being many orders of magnitude higher than a human being can hear. This method is best where the flow depth is greater than 75% of the diameter. Sound wave travel into the object being inspected and reflects whenever there is a change in the density of the material with some of the energy in the wave returning to the surface and some passes on through the new material. The technique is capable of detecting pits, voids and cracks orientations are much more difficult to detect than others. The ultrasonic wave reflects most easily when it crosses tan interface between two materials that are perpendicular to the wave. The ultrasonic beams are well to examine the sewer below the waterline and therefore complement CCTV systems, which are confined to examining a sewer above waterline.

A 9.6 A NEW AUTOMATED APPROACH FOR CULVERT INSPECTION

Automated Defect Detection for Culvert Inspection and Condition Assessment (Guo, 2008)

A number of technologies are applicable to inspect culverts, such as Closed-Circuit Television (CCTV), sonar surveys, laser surveys, and so on. CCTV is the most commonly and commercially used. Besides these technologies, companies are developing new equipment that improves data acquisition techniques and deploys multiple sensing which will be operated by an autonomous robotic device. This device automatically detects and classifies defects/critical features in the culverts and drainage systems which can be used to take decisions. A study entitled “Automated Defect Detection for Sewer Pipeline Inspection and Condition Assessment” presents automated defect detection for sewer pipeline inspection and condition assessment which can be useful for culverts and drainage structures.

Issues and Challenges of Existing Automated Visual Data Interpretation for Sewer Infrastructure

Automatically interpreting visual inspection data for culverts using advanced technologies and approaches in image processing, computer vision, and pattern recognition, it will advantageous over,

(i) Current labor-intensive visual data-based inspection and condition assessment
(ii) Sensing selection and action guidance for multi-sensor based inspection, and
(iii) Implementation of a new generation of autonomous intelligent robotic crawlers for culverts and drainage structures.

Based upon the need for interpreting inspection videos/images and monitoring, automated visual data interpretation and condition assessment can be categorized as automated detection and automated classification of structure defects and/or critical features using images and/or videos. The conventional inspection methods are labor-intensive and error-prone. Neural network-based methods for defect pattern recognition are the major method for classifying defects in structures.

Automated Detection and Recognition Model

An Automated Detection and Recognition Model focuses on the Data Processing & Interpretation module as shown in Figure A9.3. The automatic warning system warns the inspector whenever a defect or a critical pipe feature has been found. Then they could pay attention to what is being automatically displayed, in the mean time, this automated defect detection methodology is implemented for offline image/video-based condition assessment. Since only detected defects/features are needed to be classified, it saves time. If visual data has been collected using a technique such as SSET, the acquired visual data could be scanned and processed using the proposed detection methodology, and then defects/critical features would be framed automatically for certified professionals to classify them according to the standards. The latest innovative development for data acquisition motivates the need to automate culvert condition assessment. Such a system will boost automated detection of pipe defects/features and will allow the system to automatically request further sensing, and will fuse and interpret a set of comprehensive data collected by multiple sensors.

Working Procedure of the Equipment

A three-phase automated pipe condition assessment scenario is considered.

I. *Defect detection:* In this phase, the inspection robot will move at a normal speed, which is relatively fast, and will detect defect if they exists. After the potential defect is identified, the robot instructed to stop and record higher quality visual data. Form this data it is determined whether it is a real defect or a false alarm.

II. *Defect interrogation*: In the second phase if a “defect” is identified as a false alarm, the robot will keep moving. Otherwise, the robot will stop, call for further sensing, and perform an in-depth examination.

III. *Defect classification:* In this phase the defect detected will be classified automatically, either during the inspection process or offline after the inspection process, using a variety of defect classification techniques.

In the defect interrogation and classification phases, multiple sensors are used to capture different aspects of the pipe condition. The best sensor is selected by deploying a multi-agent architecture; in addition, the multiple sensor data is integrated or fused to reinforce the interrogation and classification results. To process effectively the large volumes of data collected by the robot camera during inspection of the pipeline inner wall surface, according to the above described multiphase scenario, a multilayer approach for automatic defect detection and classification of pipeline defects is devised. In the 1st process block “Detector,” the model flags Regions of Interest (ROI), such as potentially problematic areas and/or critical pipe features in the images. Each of these flagged ROIs is input to a “1st level classifier” that broadly recognizes it as a false alarm or as a defect. The defect is then input to a 2nd level classifier sequentially that further discriminates it from among several different defects, e.g., a crack, a fracture, roots, corrosion, or a lining failure. The defect, say a crack, can still be input to a classifier at the next level that determines if it is a horizontal or spiral crack. A final classifier may determine the degree of relevancy of the defect, for example, “immediate attention,” “further monitoring,” or “safe to ignore.”

With this new generation of autonomous intelligent robotic crawlers being developed, the proposed automated defect detection capability will:

1. Enable an autonomous robotic crawler to detect and frame defects and critical features.
2. Initiate automated classification, since a defect/feature can only be classified after it has been detected/recognized; and
3. Direct automated sensing selection & analysis once a defect/feature is detected, if a multi-sensor based inspection platform is used.

In detail, an automated and reliable defect detection capability can facilitate robotic intelligence and multi-sensor based pipe inspection by locating and framing ROIs, and recognizing the framed ROIs as true defects/features or false alarms (non-defects/features). Then, based upon the flagged ROIs and detection results, the intelligent crawler can make further intelligent decisions, for example:

1. Call for further sensing or other actions automatically. For example, if a true defect or pipe feature is recognized, videos or images of higher quality could be recorded for later maintenance decision support, or other inspection sensors could be started up to acquire appropriate inspection data; and
2. Guide further analysis for target recognition. For example, according to a municipal authority's need for inspection, a particular need is to identify and quantitatively measure extents of corrosion within a certain pipe segment. An automatically identified defect can be further classified as "corrosion" or "non-corrosion." If corrosion has been recognized, a laser scanner could be further used to acquire data so that a quantitative measurement could be conducted. Hence, the municipal's need for identifying and quantitatively measuring extents of corrosion can be achieved automatically.

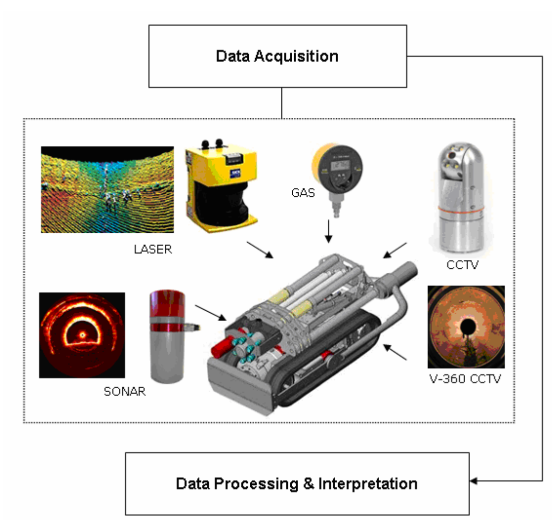


Figure A9.3: Data Processing & Interpretation module