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DEVELOPMENT OF AN ASSET MANAGEMENT MODEL
FOR CULVERT INVENTORY AND INSPECTION

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DEEPAK VARADARAJAN BHATTACHAR

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Mohammad Najafi

Major Professor's Signature

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DEVELOPMENT OF AN ASSET MANAGEMENT MODEL FOR CULVERT INVENTORY AND INSPECTION

By

Deepak Varadarajan Bhattachar

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ABSTRACT

Development of an Asset Management Model for Culvert Inventory and Inspection

By

Deepak Varadarajan Bhattachar

The deteriorating highway culvert infrastructure has become a major challenge for the 21st century. More importance was given to technical or construction methods of the highway culvert, and its maintenance and preservation was neglected. As the culverts reach the end of their design life, the state and local agencies are in need of a framework to track the existing culverts and determine its condition. The main goal of this research is to develop a framework for culvert asset inventory and condition assessment (inspection). The objectives are to study the state of practice culvert asset management in USA and Canada, develop a framework in the form of protocols and condition rating system for culvert inventory and inspection, and validate the developed framework by conducting field pilot studies. Performance score for the culverts are calculated using Analytical Hierarchy Process (AHP) to determine the magnitude of the deterioration and assist in short and long term planning. The study focuses on concrete, corrugated metal pipe (CMP) and plastic culverts spanning less than or equal to 10 feet. This model fulfills the requirements of Governmental Accounting Standards Board (GASB) 34 and contributes in having an effective culvert asset management strategy throughout the nation.

To
Patti, daddy, mummy, chitapa, chiti,
lovely sister, brothers, shubi
and my beautiful pets

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TABLE OF CONTENTS

CHAPTER 3: METHODOLOGY

CHAPTER 4: SURVEY ANALYSIS

CHAPTER 5: DEVELOPMENT OF ASSET (CULVERT) INVENTORY MODEL

CHAPTER 6: DEVELOPMENT OF CONSITION ASSESSMENT MODEL

CHAPTER 7: VALIDATION: PILOT FIELD STUDY

CHAPTER 8: CONCLUSION AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Introduction

The United States of America has the world's biggest transportation network system. The industrial growth during 1950's 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 are 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 (www.wikipedia.org).

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.

The Nation's infrastructure is the public's asset. Construction of these infrastructures is paid through tolls, utility bills, 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 Department of Transportations (DOT)'s and local governments are good managers of the public assets.

The DOTs are not aware of the fact as to what assets they own such as different types of culverts, where these assets are located, In what conditions do 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 thesis develops a model for culvert's inventory and inspection and gives an answer for all the above questions.

1.2 Background

Culverts as defined by Ohio Department of Transportation (ODOT) Culvert Management Manual (2003) are "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 the figure 1.1.

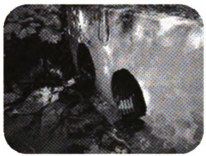


Figure 1.1: Culvert Structure
(Source: http://www.bioengineering.com/Projects/northwestbranch_anacostia.html, date visited June 11th 2006)

Culverts are physically embedded inside the earth and they are one of the most critical and expensive 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 2005). 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 a 50' section of the culvert pipe. 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.

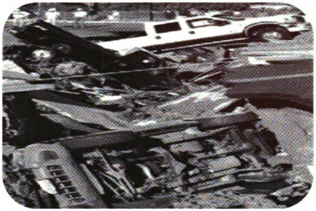


Figure 1.6: Failure of 30 year old CMP in Bakersfield, California

- 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 near by 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. The 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 cost of failed culverts and how a longer life pipe such as concrete during initial installation could have been cost effective over a longer period (Perrin, 2004).

Table 1.1: Cost Table of Recent Culvert Failure (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 AADT	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. At this point failure may occur due to factors such as excessive loads not designed for, or settlement. As the pipes tend towards their end of useful life the failure rate 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 very high.

The service life of concrete culverts in general is between 70 to 100 years. Whereas, corrugated steel or metal culverts usually fail due to corrosion of their inverts or exterior of their pipe. 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).

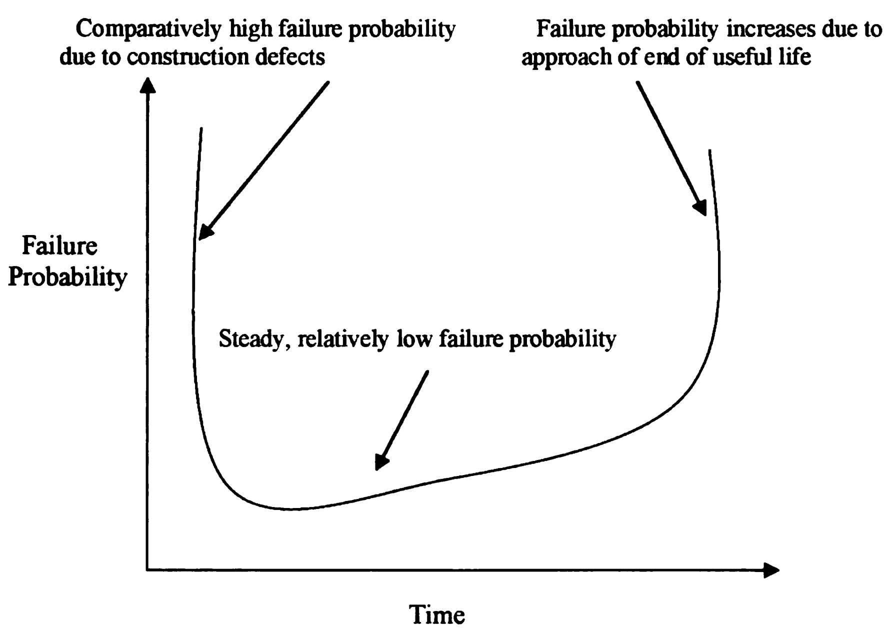


Figure 1.8: Bathtub Curve (Najafi, 2005)

1.2.1 Preserving the Deteriorating Infrastructure

Governmental Accounting and Standards Board (GASB) is a private, non profit 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 the 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 manages those assets using an asset management system that has certain characteristics and 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 demands depreciation-reporting requirement on infrastructure assets using "Modified Approach", as shown in Figure 1.9, which focuses on preservation of utilities and the following asset management components:

- 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

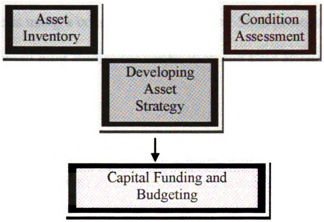


Figure 1.9: Asset Planning Framework – "A Modified Approach"

1.3 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/preventive asset management strategies. Most of the research conducted in the past focused on problems from a traditional structural/geotechnical perspective. Though this research improved our knowledge on culvert behavior, but 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, it was understood 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. This research focuses on developing a framework in the form of protocols for inventory data collection and management plus inspection of culverts using a condition rating system. Such protocols would be reviewed and then tested in small pilot studies for verification and field efficiency.

1.4 Goals and Objectives

Goal: As a part of the asset management strategy, the main goal of this research is to develop a framework for culvert asset inventory and condition assessment (inspection).

Objectives:

- To study the state-of-practice culvert asset management in USA and Canada
- To frame a model for inventory and condition assessment of culvert structures
- To validate and optimize above framework through pilot studies

1.5 Research Scope

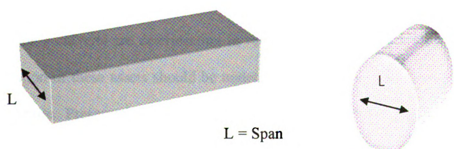


Figure 1.10: Culvert Span

This study is focused on culverts spanning equal to or less than 10' as shown in the figure 1.10. The driving force for this research is to understand and set a foundation for comprehensive asset management framework by focusing on inventory and condition assessment components. The field pilot studies are executed in and around Mid-Michigan for ease of operation and funding constraints. Culvert renewal and repair methods related to various structural, hydraulic, and environmental problems are not considered in this study.

1.6 Expected Deliverables

The research intends to solve a practical problem with a practical solution. A literature review involving the description of the culvert structure and its components, its structural and hydraulic behavior, various parameters affecting its performance, and asset management principles and framework will be presented. An inventory and inspection framework for preserving the culverts will be developed and formulas to determine the performance of the culvert will be formulated.

1.7 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. Preservation seeks to reduce the rate of deterioration. 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, 2005)

- 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

To implement such an extensive and comprehensive asset management system requires a good understanding of asset type, materials, various factors affecting their performance, reporting methods, data analysis, information management, assessment of existing programs, and practices and support services.

This chapter focuses on the main theme of the research. It gives an introduction and background to the research topic and states the need for developing an asset management inventory and inspection model. A main research goal is established and objectives to satisfy this goal are stated.

CHAPTER 2

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 an inadequate inspection and maintenance program 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 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 "Risk Assessment and Update of Inspection Procedures for Culverts." (ORITE 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. The nationwide survey they conducted indicated that 60% of state

DOT's have developed culvert inspection policies; 48% of them specify 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. Also, the report suggested appropriate rehabilitation techniques depending on structural, hydraulic, and environmental conditions of the culvert (ORITE 2005).

Another important study was done by National Cooperative Highway Research Program (NCHRP), Synthesis 303 Assessment and Rehabilitation of Existing Culverts (NCHRP, 2002). The objective of this study was to determine the state of practice of pipe assessment, the selection of appropriate repair or rehabilitation methods, and the management aspects of the pipe program. The study collected information on 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. The study determined the current management systems and methods used by transportation agencies to predict the service life of pipes. 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 rehabilitation. Most of the transportation agencies surveyed did not have methods to select the best type of pipe repair given the circumstances. Also local agencies use their respective state DOT's charts and specifications for rehabilitation 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, at a minimum, 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:

- 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).

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" (GASB1999).

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

2.3.1 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 managing 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)

2.3.2 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:

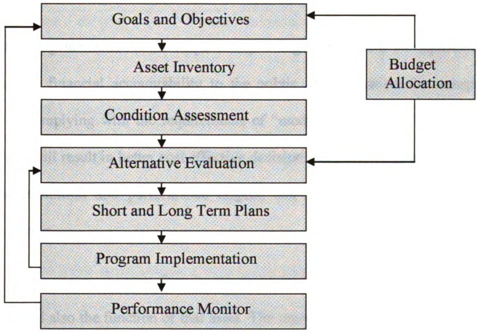


Figure 2.1: Generic Asset Management Framework

- 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

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 will result in better cost effective decisions, and improves a state's 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 also the function of that asset. The ingredients of the strategy attempts to answer the following: (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

2.4 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 DOT's, 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 DOT 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, 2006). The culvert management system allows the agency to have an inventory of culverts which includes the number and location for which the agency is responsible to the condition of culverts at any point of time, necessary repairs to fix in case of any problems, developing a short and long term plan and work schedule for culvert maintenance in future (FHWA 2001)

2.5 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

2.5.1 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

2.5.2 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. The headwater depth increases to force 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: http://www.hydrocad.net/culvert1.htm)

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.

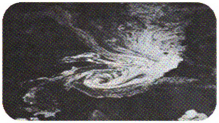


Figure 2.3: Culverts functioning as Outlet Control
(Source: http://www.hydrocad.net/culvert1.htm)

Table 2.2: Comparisons between Inlet and Outlet Control
(Source: http://www.haestad.com/library/books/fmras/floodplainonlinebook)

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

2.5.3 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: FHWA, 2001)

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:

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

Where, F_r = Froude number
V = Average velocity of flow
y_h = Hydraulic depth
g = Gravitational acceleration

If $F_r > 1.0$, then the flow is supercritical and is characterized as swift flow as shown in Figure 2.3.

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

If $F_r = 1.0$, then the flow is critical

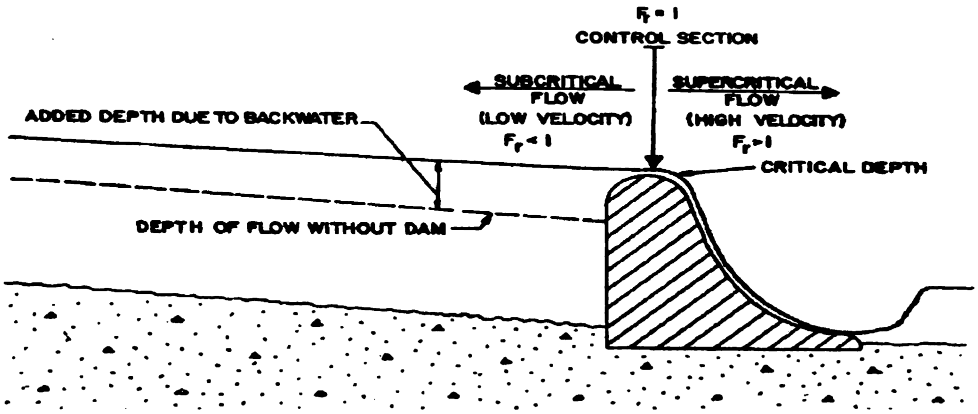


Figure 2.5: Flow Conditions
(Source: FHWA 2001)

2.5.4 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 2.6, 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.

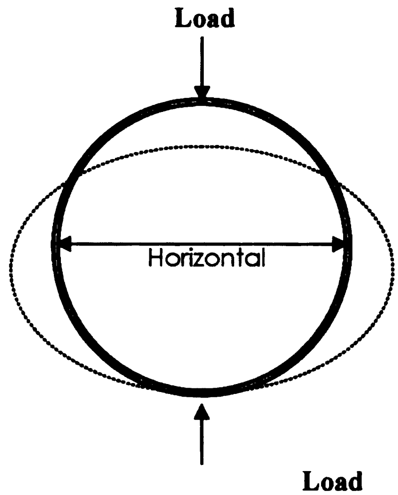


Figure 2.6: Deflection of Flexible Culverts
(Source: FHWA 1986)

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 2.7.

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.

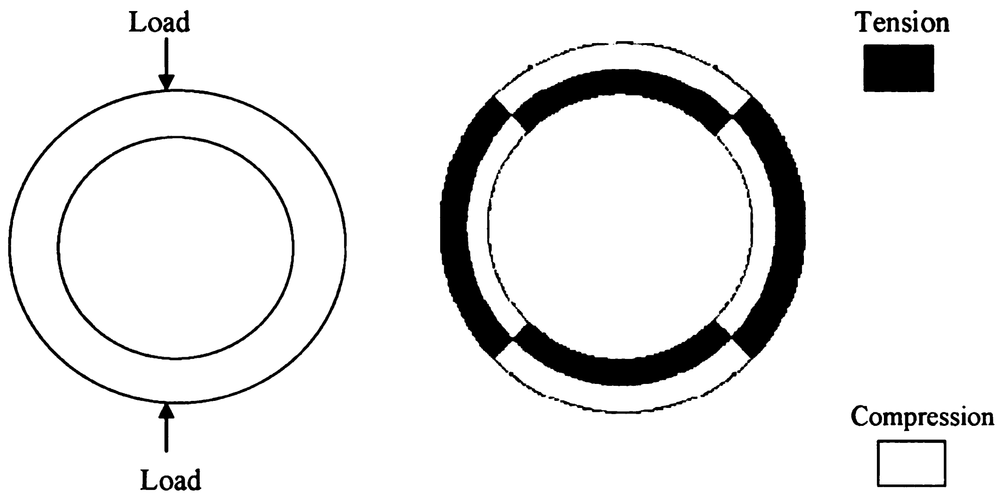


Figure 2.7: Zones of Tension and Compression in Rigid Pipes

2.5.5 Culvert Types

Culverts can be categorized based on their shapes 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. The common shapes for a culvert 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 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 2.8: Multiple Barrel Culverts
(Source: http://www.shermanconcrete.com/boxculv.htm)

2.5.6 Culvert Materials

Culverts are made up 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.

ODOT classified the different culverts according to the material in their culvert manual as shown in the Table 2.3.

Table 2.3: Culvert Classification according to their Material (ORITE 2005)

Culvert Type	Sub - Category
Corrugated Metal	Coated Corrugated Steel Pipe
	Coated with Paved Invert Corrugated Steel Pipe
	Galvanized Corrugated Steel Pipe
	Corrugated Metal, Pipe Use with Shape Code 1 only
	Corrugated Metal, Non Sectional Plate Use with Shape Code 2, 3, 4
	Corrugated Metal, Sectional Plate Use with Shape Code 1, 2, 3, 5, 6, 7
	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
Concrete	Plain or Reinforced Concrete
	Corrugated Plastic Smooth Interior
Plastic	Corrugated Plastic
	Polyvinyl Chloride
	High Density Polyethylene Liner

2.5.6.1 Corrugated Metal Culverts

Corrugated Metal Culverts (CMP) is one of the oldest culvert material used in US, other than concrete. With greatest 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, quoted the following advantages of Corrugated Steel 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 content. 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 (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 (Shen 1994).

2.5.6.2 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 (Heger, 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 atleast one diameter.

The performance of concrete culverts depends on the pH of the flow, age of the culvert, sediment depth, slope, presence of roadway de-icing 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 in harder.

2.5.6.3 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 plastics are Polyvinyl Chloride (PVC) and High Density Polyethylene (HDPE). Both are unaffected by the chemical and corrosive elements typically found in soils. They have exhibited excellent abrasive resistance, particularly when acidic or alkaline conditions are present.

ORITE has investigated ten culverts and the most frequently observed problem was the deflection of the pipes. Localized buckling was the second most frequent problem followed by misalignment problems at the joints.

Gassman et.al conducted investigation on forty five HDPE culverts in South Carolina. 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.

Plastic pipes can be manufactured with a desired durability to with stand the effects of corrosion and abrasion. However, installation and backfilling procedures have to be handled with care.

2.5.7 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:

- Headwall or Endwall
- Wingwall
- Energy Dissipators
- Aprons
- Fish Passage Device
- Projecting

- Skewed
- Mitered

Headwall - Headwalls 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.

Wingwall – Wingwalls 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

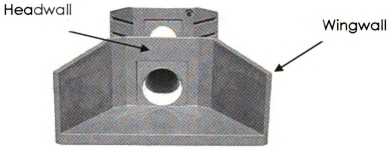


Figure 2.9: Culvert showing Headwall and Wingwall
(Source: www.tankmasta.com.au/ images/Rural/Culvert.jpg)

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.

Energy Dissipators – Energy dissipators 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 dissipators 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. *Drop structures* changes 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 2.10: Riprap Basin to Protect Streambed and Stream Slope
(Source: www.tankmasta.com.au/ images/Rural/Culvert.jpg)

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.

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 vertical barriers are too high for fish to overcome. Other problems include when depth of water in the culvert are at high, moderate, or low flows which may not be 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 or by providing fish ladders, backwater structures like weirs, gabions, etc, and a fish pool at the culvert outlet can be provided.

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.

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 also called as beveled end.

Skewed End – Culverts which 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.

2.6 Factors Influencing Performance of a Culvert (AASHTO, 1999)

Performance of a culvert is directly proportional to its remaining design service life. 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 manufacture, or handling of the culvert.

Major factors influencing the performance or service life of a culvert are:

- Durability factors
    - Corrosion

- Abrasion
- Loss of Structural Integrity
  - Joint Separation
  - Misalignment
  - Deflection
  - Seam Defects
  - Stream or Roadway Embankment Erosion
- Environmental Factors
  - Scaling
  - Delamination
  - Spalling
  - Chloride Contamination
  - Efflorescence
  - Honeycombs
  - Pop-Outs
  - Collision Damage
  - Scouring

2.6.1 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 - 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. *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.

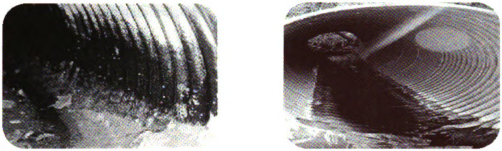


Figure 2.11: Corrosion in Culverts (Caltrans, 2003)

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 to be 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. But, 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 bedload and suspended material. Abrasive potential is a function of culvert material, frequency, velocity of flow in the culvert, and composition of bedload. 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. Large volume of debris can increase bedload abrasion. The most common types of debris found in culverts are boulders, trees, shrubs, ice, etc.

Figure 2.12: Debris at the opening of the culvert
(Source:http://www.ctre.iastate.edu/pubs/tech_news/2005/mar-apr/debris-at-culvert.jpg)

Bedload – Bedload is the main cause for abrasion. Critical factors in evaluating bedload potential are the size, shape, and hardness of the bedload material, and the velocity and frequency of flow in the culvert. Flow velocities greater than 4.5 m/sec which carry a bedload are considered to be 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.

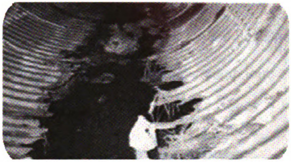


Figure 2.13: Deterioration due to Abrasion (Caltrans, 2003)

2.6.2 Loss of Structural Integrity

Loss of structural integrity shortens the service life of culverts or affects its performance. They are due to defect 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.

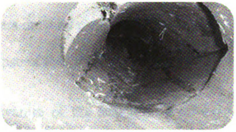


Figure 2.14: Culvert Pipe showing Cracks and Joint Separation
(Source: http://www.lagunabeachcity.net/government/departments/waterquality/image002.jpg)

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 shape and curvature of the structure is affected by the lapped and bolted longitudinal seams. 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 develops along the bolt holes 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 bolts tip, and the bolt holes are plastically elongated by the bolt shank. 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 2.15.

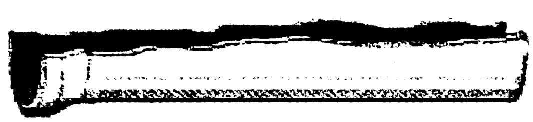


Figure 2.15: Longitudinal Crack in a Culvert Pipe
(Source: http://irc.nrc-cnrc.gc.ca/images/ui/figure23.jpg)

Transverse Cracks - Transverse cracks or circumferential cracks are caused by poor bedding. 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.

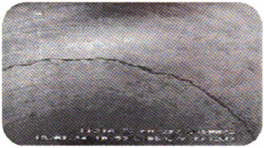


Figure 2.16: Transverse Cracks in a Culvert Pipe
(Source: Caltrans 2003)

2.6.3 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 the aggregate and may involve loss of upto 1/8 to 3/8 inch of the surface mortar. In severe scaling, more surfaces will be lost and the aggregate is separated and exposed. (NRMCA, 1998)

Figure 2.17: Scaling exposed on Concrete Surface
(Source: http://www.pci-potomac.com/faq/scaling.jpg)

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 2.18: Delamination on a Concrete Surface
(Source: http://www.cdcrestoration.com/structural.html)

Spalling – spalling is a depression in concrete caused by a separation of a portion of the surface concrete where the topping in 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.

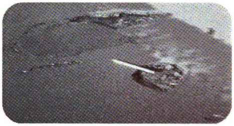


Figure 2.19: Spalling on a Concrete Surface
(Source: Caltrans, 2003)

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.

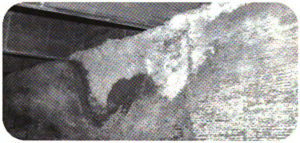


Figure 2.20: Formation of Efflorescence on a Concrete Surface
(Source: http://www.housecheckguide.com/photos/600tall/fig-37.jpg)

Honeycombs – Honeycombs are coarse aggregate 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 2.21: Honeycombing on a concrete surface (Source: http://www.arche.ps u.edu/thinshells/module%20III/concrete_behavior_text_files/ image020.jpg)

Popouts – Popouts are conical fragments that break out of the surface of the concrete leaving small holes as shown in Figure 2.22. Popouts occur because the concrete has been overworked, allowing the aggregates to drift upward toward the surface.

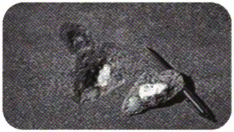


Figure 2.22: Popouts in a Concrete Structure
(Source: http://www.vseal.com/surfacedefects/images/popoutsa.jpg)

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

- Size, shape, hardness, and volume of bedload
- Volume, velocity, and frequency of streamflow 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)

2.7 Summary

This chapter reviews various concepts and principles of culvert asset management. The enforcement of GASB 34 in 1999 requires 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 customer focus and mission driven. It results in cost saving over the emergency repair of culvert failures which is an increasing problem in the nation.

Understanding the engineering aspects of the culvert is very necessary in developing an inventory and inspection model. This chapter briefly explains hydraulic and structural concepts like inlet control, outlet control, types of flow, flexible and rigid culvert behavior, culvert types based on shape and material identifies various culvert components like culvert appurtenances and end treatment and lists the various factors contributing to culvert deterioration such as durability, loss of structural integration, and environmental.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Chapter one of the thesis illustrated the importance of an inventory and inspection model in framing an effective asset management strategy to preserve our deteriorating culverts; it also explained the need for this research and presented goals and objectives for this project. Chapter two focused on the asset management principles, engineering considerations of culverts, factors affecting their performance, and culvert asset management. Chapter three presents the process in developing inventory and inspection models that would facilitate the objectives of this research. This research is carried out in five phases and is explained with respect to the proposed objectives.

3.2 Phase 1: Literature Review

Objective: To study the state of practice culvert asset management

Literature was reviewed to study the state of practice culvert asset management. The study focuses on various components of a culvert and its structural and hydraulic behavior. This facilitates identifying the key components for detailed inventory of the culverts. Reviewing various concepts affecting the performance or the service life of a culvert, existing inspection, data analysis, and reporting methods gives us an insight in developing condition assessment model. A national survey was conducted in all fifty states of the US and ten provinces of Canada to study the implementation of culvert inventory and inspection in addition to asset management strategy.

3.2.1 Developing Questionnaire

A questionnaire is an instrument for collecting data for a particular survey. It consists of a series of written questions for which respondents provide complete and accurate information. Questionnaires are a valuable method of collecting a wide range of information from a large number of respondents. The steps followed in developing a survey questionnaire are:

- Determine the goals and objectives of the survey
- Determine the general question content needed to obtain information
- Choose a question type based on interview method
- Determine the form of response
- Choose the exact question wording
- Arrange the questions into an effective sequence
- Categorize the questions based on type of information sought
- Give an introduction and provide a consent form for the respondents
- Test the questionnaire and revise it if needed (www.quickmba.com)

The objective of this survey questionnaire is to understand the current developments in inventory and inspection of culverts spanning less than 10 feet (diameter or opening length) in the US and Canada. Based on the feedback, the existing literature on culvert inventory and inspection procedures will be collected and later checked with the proposed research model. This survey would highlight the importance of this research by giving us an idea about culvert deterioration and the necessity of asset management in preserving them.

3.2.2 Interview Method

There are twenty six questions in this survey, most of which are closed ended questions giving the respondents with three choices – "Yes" "No" and "Development Phase." It is estimated to take less than 15 minutes to complete this survey. The respondents are given three options for answering:

1. Web format, which is strongly recommended. The survey was designed in Hosted Survey software (www.hostedsurvey.com) and hosted on their server. All the respondents was sent an email with the survey link:

http://www.hostedsurvey.com/takesurvey.asp?c=AnAsse155751

2. PDF format of the survey questionnaire was sent to all respondents with the web format. They could answer the survey and fax it to the Center for Underground Infrastructure Research and Education (CUIRE) at (517)432-4937.

3. Telephone interview, where the respondents will be sent CUIRE telephone number – (517)335 – 3885 and they could call and give their answers.

All the fifty Department of Transportation (DOT)'s in the US and ten Provinces in Canada were contacted. The best person to answer this survey in either Highway Maintenance Division or Asset Management Division or Bridge Management Division or Hydraulics Division was identified. All the details of the research are explained and their consent to participate is taken.

The prepared questionnaire will be submitted for approval to the CUIRE team which consists of Dr. Mohammad Najafi, Director, CUIRE and Peter Funkhouser, Engineer, Michigan Department of Transportation (MDOT); The oversite committee which consists of industry professionals Mr. Dave Kozman, American Water Services, Mr. Troy Freed, SOS Service Group, Mr. Shiv Gupta, Wisconsin Department of Transportation (WDOT), Mr. Greg Wadley, Midwest Regional University Transportation Center (MRUTC), Mr. Terry McArthur, HDR; and to the University Committee on Research Involving Human Subjects (UCRIHS). UCRIHS reviewers the survey instrument to make sure that human related matter were handled as per the rules and regulations.

Once all approvals were received and necessary revisions were made, the survey instrument was mailed to all the respondents. All the responses were collected in the Hostedsurvey server and a database of all the agencies responded was maintained in a Microsoft Excel sheet. A total of three reminders was sent to all the unanswered respondents, one every week for three weeks.

3.2.3 Data Analysis & Results

The collected data was recorded in Excel format. Because of the small sample size of thirty three, a statistical study of the data will not be carried out, so a qualitative analysis of the data will be used. The responses was evaluated and separated into different categories. The entire background of the respondent, his/her technical knowledge, and experience in culvert inspection and management will be given significance in drawing the conclusion.

3.3 Phase 2: Inventory Model

Objective: Development of inventory protocol

Based on through literature review in phase 1 of the methodology, survey, and discussion with the industry professionals, a data collection format or the inventory database was developed. The concept of whole to part will be implemented, where the identification starts from state level (Ex: Culverts in Michigan) to very specific component of the culvert. A coding system was followed throughout the data collection format to create a platform for Global Positioning System (GPS) and Geographical Information System (GIS). Most of the coding system follows national standards like the Federal Information Processing System (FIPS). This inventory database was accompanied by a coding manual, which defines all the details and codes. All the culverts will be assigned a unique identification number (UI) for linking them to GIS and other financial softwares used by the DOT's. This inventory database will be the foundation in developing a condition assessment or inspection model for culverts.

3.4 Phase 3: Condition Assessment Model

Objective: Development of inspection or condition assessment protocol, condition rating system, and performance score calculator.

The development of a condition assessment system requires a good understanding of the structural and hydraulic performance of the culverts, various factors that affect their service life, and contribute towards their deterioration, existing inspection and repair procedures for other or similar structures like bridges, guardrails, etc., and thorough management and statistics knowledge. The condition assessment system was divided into two parts:

- Basic Condition Assessment
- Advanced Condition Assessment

In basic condition assessment, only the major components of the culvert will be inspected and will be assigned a rating between 5 – 0, where 5 represents excellent or new condition and 0 represents failed condition. Using Analytical Hierarchy Process (AHP), "*a decision making process which involves structuring multiple choice criteria into hierarchy, assessing the relative importance of these criteria, comparing alternatives for each criterion, and determining overall ranking of the alternatives*" (http://www.rfp-templates.com/Analytical-Hierarchy-Process-(AHP).html), a matrix will be developed for all the major components of the culvert and a relative weight will be assigned to them. Using the relative weights of all the components, a performance score calculator will be established and all the culverts will be categorized into three zones as follows:

- Green zone or safe zone
- Yellow zone or intermediate zone
- Red zone or danger zone

Short and long term plans for culvert inspection will be proposed based on these categories. But, for the culverts in the red zone or danger zone, which need immediate attention, advanced condition assessment will be performed.

In advanced condition assessment, all the structural, hydraulic, and environmental parameters influencing the performance or service life of the culvert will be identified. These parameters are given a rating system between 5 – 0, where a rating of 5 would indicate a very minor problem and a rating of 0 would indicate a very severe or major problem. Again, using AHP performance, factors were determined for all culverts. Using the performance factors of the advanced condition assessment, two formulas were developed:

- Percent Performance Improvement Factor
- Percent Performance Deterioration Factor will be formulated

3.5 Phase 4: Validation

Objective: Validating the above models

The above models are validated using two procedures:

- Carrying out the pilot field study

- Discussion with the industry professionals and Michigan DOT officials

Validating is an important phase in any research process, as the theoretical models and frameworks should go well with the practical problem. Using the As-Built plans from Michigan DOT, maintenance division, the culvert sites in and around Mid-Michigan will be located. All the safety and inspecting permits from related agencies will be obtained before going to the culvert sites. Culvert inventory and basic condition assessment are conducted together. First, the culvert is tracked using the data collection format accompanied by the culvert inventory coding manual. Using the basic condition rating system, the major components of each culvert are inspected and documented in the condition assessment format. Then the overall culvert performance factor is determined and the culvert is categorized into the three zones defined in phase three. All the culverts identified under red or danger zone are subjected to advanced condition assessment. Using the advanced condition assessment rating system, all the details are documented in the respective format. Finally, the performance factor is determined and recorded.

Another validating procedure is the discussion with the industry professionals and Michigan DOT officials. Once the inventory and inspection model is developed, a meeting will be arranged in the CUIRE office. A Microsoft PowerPoint presentation of the models will be presented to the officials. Feedback from the discussion will be documented and later necessary revisions will be incorporated in the models. Similarly, the models will be emailed to all the over-site industry professionals and a teleconference will be arranged in the CUIRE office. The discussion will be documented and later any suggestions or revisions will be incorporated in the inventory and inspection models.

3.6 Phase 5: Conclusion

Objective: Conclusion and Recommendation for implementing effective culvert asset management strategy.

This phase summarizes all the steps adopted in the methodology to complete this research. Based on the discussion with the Michigan DOT officials and industry professionals, practical recommendations will be suggested for implementing this research on a large scale. The recommendations will be useful in developing short and long term plans. Also, areas for future research and development related to culvert asset management will be proposed.

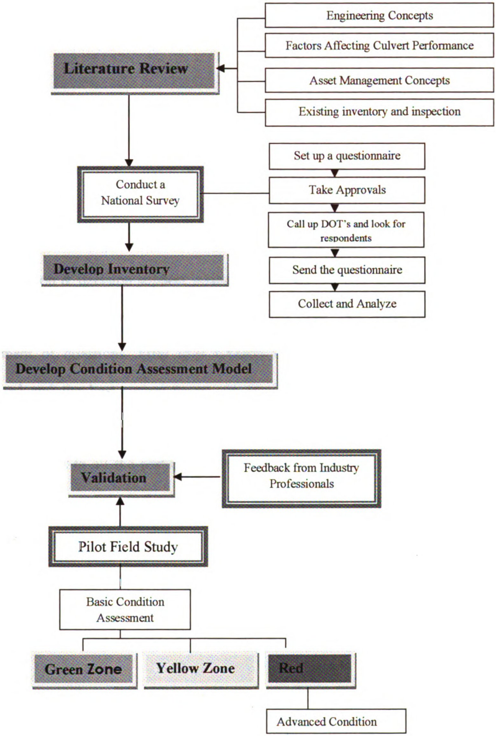


Figure 3.1: Detailed Methodology

CHAPTER 4

SURVEY RESULTS AND DATA ANALYSIS

4.1 Introduction:

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 return with the questionnaire for logical assessment of questions. Fifty (50) USDOT's and ten (10) Canadian DOT's were contacted and the best person to answer the survey was identified based on his/her designation, 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 a private server. A simple statistical analysis was performed to analyze the importance of culvert asset management. Table 4.1 shows the US States and Canadian Provinces participated in the survey.

Table 4.1: 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

4.2 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 (81%) of the respondents felt that the culverts in their state were in good condition and has not given any indications of reaching their useful service life. Six percent (6%) of the respondents felt that their culvert was 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 are in the verge of their useful service life and need some type of assessment protocols to track and assess their condition. The figure 4.1 and 4.2 shows the condition of majority of culverts in US and Canada.

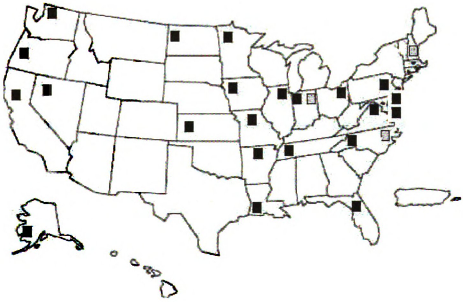


Figure 4.1: Condition of Majority of Culverts in United States

Color Condition

■ Very Good

■ Good (continued...)

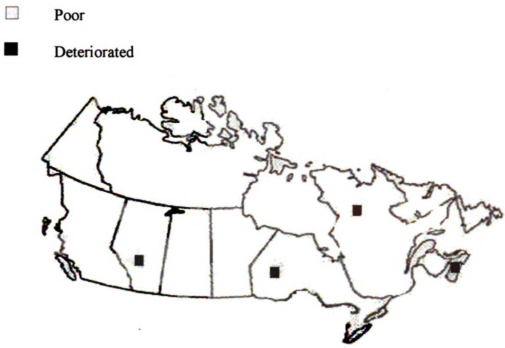


Figure 4.2: Condition of Majority of Culverts in Canada

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

This question was intended to study the type of guidelines the DOT's are following in tracking their culverts. These guidelines would give a base to develop our inventory framework. The response rate for this question was 85.3%. Sixty two percent (62%) of the respondents answered that they had some form of tracking system for the large culverts. Whereas, they had no tracking system for smaller culverts spanning less than 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 a 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 don't 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. The figures 4.3 and 4.4 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 4.3: States that have Developed Standard Set of Guidelines for Culvert Inventory in United States

● Yes, there is a form of tracking system (continued...)

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

○ Development Phase

Figure 4.4: 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 4.2 shows the different size ranges for concrete, metal and plastic culverts.

Table 4.2: Max and Min Culvert Sizes in United States and Canada

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

4. Original design of majority of culverts are based on – 10, 20, 50, 100 or other year flood?

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. The figure 4.5 shows the graph of number of responses to the culvert's design. Also, figures 4.6 and 4.7 shows the location of these designed culverts in United States and Canada.

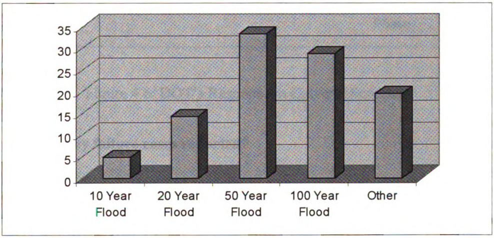


Figure 4.5: Graph of Number of Responses to Culvert Design

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 (70.58% response rate). Eleven (11) DOT's indicated that they have some kind of culvert dictionary or checklist for culvert inventory and inspection. Four (4) DOT's are in the process of developing a culvert dictionary. The figure 4.6 is the graph depicting the survey results.

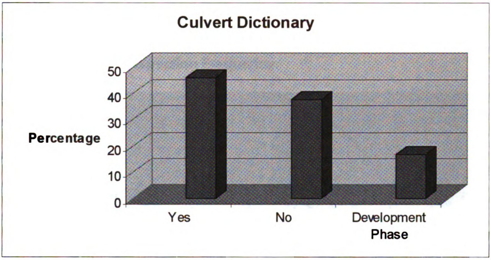


Figure 4.6: DOT's Response to Culvert Dictionary

6. Do you have any failure cases reported?

The objective of this question was to understand if DOT's 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 DOT's 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. The figure 4.7 shows the inspection frequencies and DOT responses.

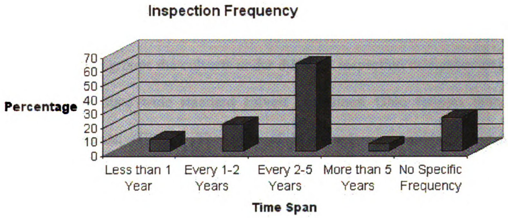


Figure 4.7: Culvert Inspection Frequencies

4.3 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 also 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) DOT's responded to this question at a response rate of 76.5%. 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). The figures 4.8 and 4.9 show the graphical representation of the US states and Canadian provinces having culvert inspection guidelines.

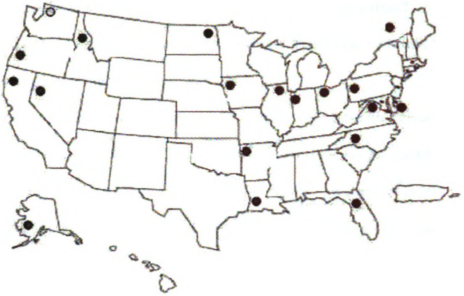


Figure 4.8 Establishment of Inspection Guidelines for Culverts – US DOT's

● Yes

● No

○ Development Phase

Figure 4.9: 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 DOT's. The graph 4.10 shows the number (expressed in percentage) of DOT's 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.

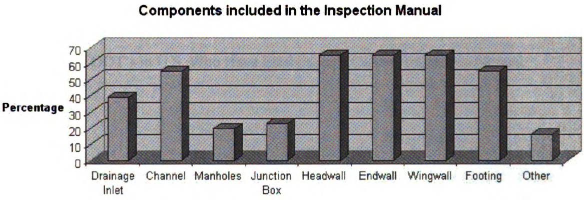


Figure 4.10: Graph Showing the Percentage Importance Given to Culvert Components in Inspection Guidelines and Manuals by DOT's

10. Does your agency have an inspection manual?

This question was framed to check if the DOT's 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 4.11 and 4.12, twelve (12)

DOT's had compiled their guidelines in the form of an inspection manual, eleven (11) DOT's had not compiled their guidelines in the form of a manual and two (2) DOT's were in the development stage of the manual.

Figure 4.11: DOT's in U.S. Who Have Established a Culvert Inspection Manual

Yes

No

Development Phase

Figure 4.12 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) DOT's responded to this question at a response rate of 82.35 percent. 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. Similarly, figure 4.13 shows the factors considered in inspection guidelines for concrete culverts.

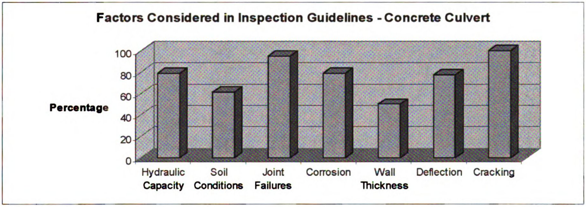


Figure 4.13: Factors Considered in Inspection Guidelines for Concrete Culverts

Hydraulic capacity, joint failures, corrosion and deflection was 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 need renovation/replacement. This question focused on determining the important factors considered by DOT in deciding replacement or renovation of a culvert. According to the responders (fig 4.14) structural problems (96%) were the no 1 factor followed by hydraulic problems (84%), material degradation (76%), deflection (68%), inspection results (64%), roadway surface (52%), age of culverts (40%), others (4%).

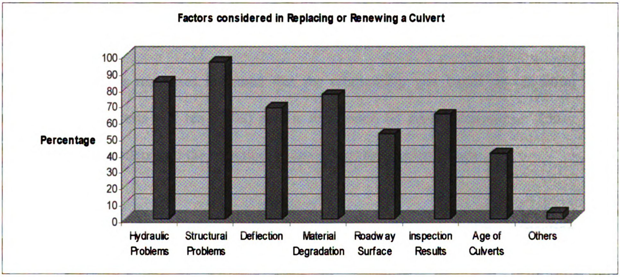


Figure 4.14: Factors Considered in Replacing or Renewing a Culvert

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 or useful life of culverts. Seventy Eight (78%) of the respondents answered that they had no model to predict the service life of culverts, thirteen (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 (60%) of the responses indicated that the relationship was based on condition assessment of culverts and ten (10%) said it was based on other relationship. Thirty (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 DOT's in inspecting their culverts. Twenty Six (26%) of the responses indicated that DOT's use CCTV to inspect and analyze the condition of their culverts, thirty five (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 (39%) of the respondents use other methods. The states of Iowa, Maryland, Delaware and Washington monitors and tests 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 don't inspect smaller culverts (less than 18"). 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?

Table 4.3: 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 flowlines
Delaware	Corrosion
Indiana	Deterioration of barrels due to rust and cracks
Ohio	Corrosion, deflection
Oregon	Crushed end sections

Table 4.4: 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 (47%) of the responses indicated that DOT's use point source repair, forty two (42%) grouting, and twenty six (26%) internal seal method for culvert structural and hydraulic problems. The other methods used by different states (37%) are as shown in Table 4.5:

Table 4.5: 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, Slip Lining, Pipe Bursting, Other)

Culvert renewal is the process of providing a new design life to the existing pipeline system. Sixty four (64%) of the respondents indicated that they would use Slip Lining methods of renewal for problems mentioned in question 16, followed by Cured In Place

Pipe (18%) and Pipe Bursting (8%). Twenty three (23%) of the DOT's mentioned other types of renewal methods as shown in the table below:

Table 4.6: Culvert Renewal Methods Followed in Various States

State	Renewal Methods
Louisiana	Culvert replacement
Virginia	Sleeving
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 DOT's to track and monitor culverts. Fifty two (52%) of the respondents said they had some kind of tracking and monitoring system for culverts and nineteen (19%) of DOT's 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 uses PONTIS, California stores all their culvert information in MS ACCESS, Alaska, Indiana, Ohio and Alberta has their own in-house software and Ontario has OBMS in visual basics.

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

A Decision Support System (DSS) is a computerized system for helping making decisions between alternatives based on estimates of the values of those alternatives (www.wikipedia.org). Managing hundreds of thousands of culverts is a challenging task and need a good DSS designed as a part of state asset management program. As per figs 4.15 and 4.16 total of twenty three (23) DOT's responded to this question and eighty three (83%) of the respondents said they had no DSS for culverts. Thirteen percent (13%) said they had some kind of DSS and four (4%) of the states 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 4.15: USDOT's having DSS

● Yes

● No

○ Development Phase

Figure 4.16: 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 DOT's had an artificial intelligence or formula to determine the performance of culverts. A total of sixty two (62%) responded to this question. As per figs 4.17 and 4.18, sixty seven (67%) of the DOT's responded that they had no model to determine the performance of culverts. Nineteen (19%) of the DOT's had some model to determine the culvert performance. The state of Virginia and Delaware uses PONTIS to assess the culvert performance. The province of Quebec integrates the anticipated intervention timeframe with culvert condition rating to determine the number of years it would perform as designed.

Figure 4.17: USDOT's having a Model to Determine Culvert Performance Factor

● Yes

● No

○ Development Phase

Figure 4.18: 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 (68%). The rating system was –

7 – 9 = Very important

3 – 6 = important

Less than 3 = Not so important

As per the fig 4.19, thirty (30%) of the DOT's responded that culvert asset management was very important (rating – 7), seventeen (17%) responded as important (rating 5) and four (4%) as not so important (rating – 3). Figs 4.20 and 4.21 show the rating system for different states in US and Canada.

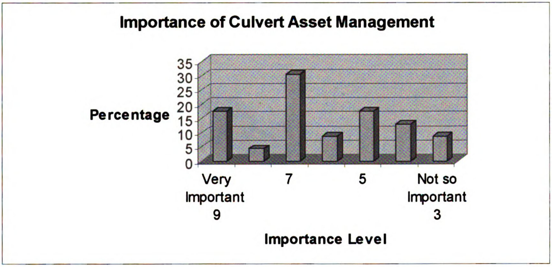


Figure 4.19: Graph indicating the Culvert Asset Management Importance Rating System

Figure 4.20: Culvert Asset management Importance Rating System in US

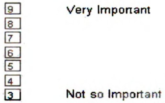


Figure 4.21: Culvert Asset Management Importance Rating System in Canada

4.4 Summary:

Culvert asset management is a relatively new concept in USA and Canada. The awareness to implement culvert asset management in every state is growing due to the number of sudden collapses of culverts. The survey indicates that eighty one (81%) of the DOT's feel that their culverts are in good condition. This is the right time for DOT's to track and maintain a good database of culverts with their condition information to avoid future disasters. We also understood from the survey that there are some form of guidelines to track and inspect large culverts (opening 3' or above). Most of the culverts are designed for 50-year flood and are inspected every 2-5 years. Most of the 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 the 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 (30%) of the respondents voted culvert asset management as an very important concept in preserving our deteriorating infrastructure.

CHAPTER 5

DEVELOPMENT OF AN ASSET (CULVERT) INVENTORY MODEL

5.1 Introduction

An inventory model is an important component of a good asset management framework. It helps the state and local agencies to measure the current level of service their assets deliver 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 rehabilitation 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.

5.2 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

5.3 Asset (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 protocol used to identify the culverts. The identification includes logical details of the culvert, its components, and the surrounding area. Once the culverts are identified and entered in the inventory database using a unique identification number, it 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 given in the inventory manual (Appendix). The coding is of two types:

- 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 Asbuilt 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 shall be determined for the route under which culvert exists.
- *Approach Roadway Width*: the width of the roadway above the culvert shall be determined.
- *Culvert marker*: the type of culvert marker used in identification shall be 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 guard rails. The identification and assessment of these features are a part of highway safety for travelers. Also, 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 rehabilitation 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 Rehabilitation and date rehabilitated*

5.4 Summary

This chapter is about the development of a culvert inventory model. The output of the model is a protocol with useful a set of questions. The six modules of the model cover all the necessary details for implementation of an effective asset management framework in the state. 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 equipments
- Proper storage and management of the collected data
- Establishing standard procedures for collecting data

Some of the terminologies in the protocol and pictures in the manual is derived from ORITE (2005).

CHAPTER 6

DEVELOPMENT OF CONDITION ASSESSMENT MODEL

6.1 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 6.1 (EPA, 2005)

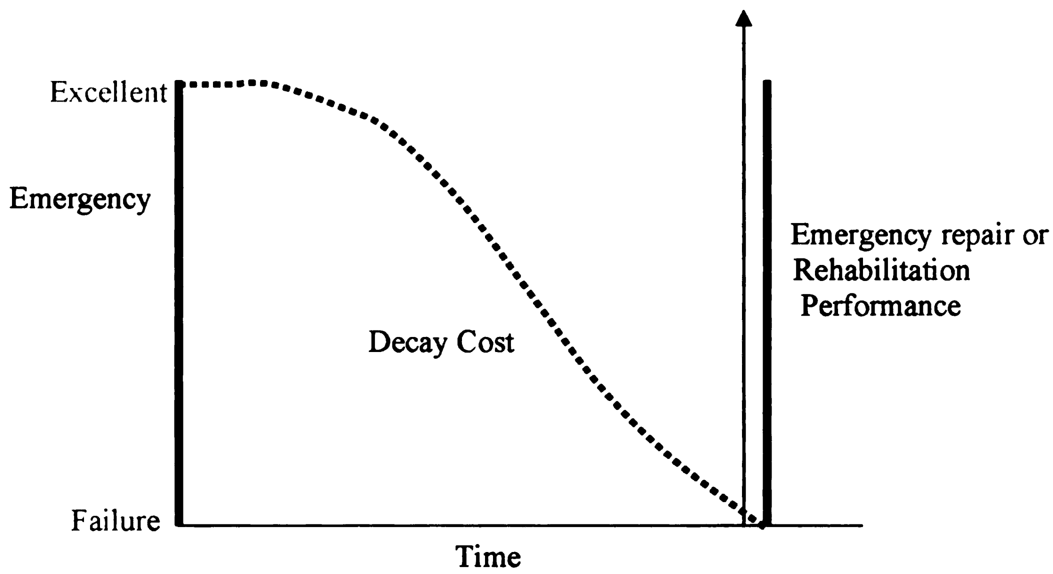


Figure 6.1: Asset Deterioration Curve

The lack of knowledge of the condition of culverts, duration of its use and remaining service life, it is difficult to determine which improvements to make and when to make 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). 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

6.2 Condition Assessment Model

The condition assessment model is a set of protocols that identifies the culverts which are underperforming, determine the reason for its deficiency, predict when failure is likely to occur and develop short and long term plans for its preservation. This model is based on the inventory model developed in chapter 5, literature review, survey, field studies and discussion with the Department of Transportations (DOT). The condition assessment model is divided into two categories:

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

6.2.1 Basic Condition Assessment

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 6.1 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:

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

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

Table 6.1: Condition Rating

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

Module one of the basic condition assessment 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, 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 indicate the deterioration of the culvert and its components. Also, 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 6.1, 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 Inverts

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 6.2 gives the condition rating system for culvert inverts.

Table 6.2: 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)

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 g.3 gives the condition rating system for end protection.

Table 6.3: 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

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 6.4 gives the condition rating system for roadway.

Table 6.4: 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

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 6.5 gives the condition rating system for culvert embankments.

Table 6.5: 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

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 6.6.

Table 6.6: 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 6.7.

Table 6.7: 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. The following Table 6.8 is used for pair wise comparison.

Table 6.8: 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 6.9. The values entered in the matrix of comparison are based on the researcher's knowledge in culvert inspection and maintenance.

Table 6.9: Matrix of Comparison for Culvert Performance Calculation

	Culvert	*Invert*	*End Treat*	*Footing*	*Roadway*	*Embankment*
Culvert	1	3	3	3	5	5
Inverts	0.2	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
	2.266	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 + 0.2 + 0.333 + 0.333 + 0.2 + 0.2) = 2.266. Thus, new values in the first column are (1/2.666) = 0.4413, (0.2/2.2666) = 0.0882, (0.333/2.2666) = 0.1469, (0.333/2.2666) = 0.1469, (0.2/2.2666) = 0.0882, (0.2/2.2666) = 0.0882. The normalized matrix looks as follows:

Table 6.10: Normalized Matrix for Culvert Performance Calculation

	Culvert	*Invert*	*End Treat*	*Footing*	*Roadway*	*Embank ment*
Culverts	0.4413	0.5454	0.4000	0.3428	0.2941	0.3333
Inverts	0.0882	0.1818	0.2666	0.2285	0.2352	0.2666
End Treat	0.1469	0.0909	0.1333	0.2285	0.1176	0.1333
Footing	0.1469	0.0909	0.0666	0.1142	0.2352	0.1333
Roadway	0.0882	0.0454	0.0666	0.0285	0.0588	0.0666
Embankmen t	0.0882	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. So, for the first row, the new value is (0.4413 + 0.5454 + 0.4000 + 0.3428 + 0.2941 + 0.3333) / 6 = 0.3920. 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 6.11.

Table 6.11: Relative Weights of the Culvert Components

Type	Relative Weights
Overall Culvert Condition	0.39280
Condition of Inverts	0.21115
Condition of End Treat.	0.14175
Condition of Footings	0.13118
Condition of Roadway	0.05901
Condition of Embankment	0.06378

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

Performance Score of the culvert = $\sum$ 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 – Red, Yellow and Green. The maximum score a culvert can obtain is 5.0 and minimum is 0. The scoring system is as shown in the Table 6.12.

Table 6.12: Culvert Performance Zones

Performance Score	Zone	Zone Meaning
Above 3.5	Green	Safe
3.5 – 2.5	Yellow	Intermediate
Below 2.5	Red	Danger

6.2.3 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 (APPENDIX). 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 problems as shown in Tables 6.13, 6.14 and 6.15. Performance score for the culvert is calculated for the culvert using the formula:

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

Then, the inspector recommends repair or rehabilitation 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 formula given below:

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

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 rehabilitation of the culvert

Table 6.13: ACA Condition Rating Factors and their Relative Weight for Concrete Culverts

Condition Rating Factors	Relative Weight
Cracking	0.3170
Scouring	0.1703
Settlement	0.1563
Joint Opening	0.1521
Misalignment	0.1348
Concrete Surface	0.0690

Table 6.14: 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

6.3 Summary

This chapter discusses in detail the development of the condition assessment model for culvert asset management. The need and benefits of condition assessment model is discussed in first section. The condition assessment model is a set of protocols to identify the deteriorating culverts and is divided into two categories – Basic condition assessment and advanced 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 the performance score. Based on the performance scores, the culvert is categorized into three zones – green, yellow and red. Culverts in red 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 7

VALIDATION: PILOT FIELD STUDY

7.1 Introduction

In chapter four and five, the culvert inventory and inspection model was developed as a part of effective asset management framework. In this chapter, the model will be applied in tracking and inspecting culverts in Lansing, Michigan. The objective of inventory model is to assign a unique identification number for all the culverts and collect relevant site information. Whereas, the objective of inspection model is to perform the basic condition assessment of the culverts against the condition rating system developed, calculate its performance score and categorize the culvert into three zones as mentioned in the chapter five. If a culvert is labeled as red zone, then advanced condition assessment is carried out and ACA performance score is calculated. This field pilot study will help in validating and measuring the feasibility of the developed model. Also, application of the model will be discussed with the MDOT highway maintenance officials and over-site committee who consists of industry people. The feedback will be recorded and necessary changes will be implemented in the model.

7.2 Pilot Field Study

This section 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; about 500 culverts there were on the verge of deterioration. An old inventory list (Appendix 6) and as-built drawing of the highway M 13 was studied to find location of the culverts. Permission from MDOT was obtained to inspect the public utility (culverts) on the highway M 13. 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. A confined space is defined to mean space which is large enough for an employee to enter and perform the assigned work.

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 3):

- 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 digit

Structure Number – A01 was coded as the structure number as it was the first culvert in the direction of inventory

So, the 11 digit unique identification number for culvert 1 is – 25001273A01. The identification number for other culverts is as shown in the Table 6.1.

Table 7.1: 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 5. 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" 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 fig 7.1. 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 (fig 6.2). The road above the culvert looked new and was in excellent condition. The condition rating for this culvert is as shown in the Table 7.2.

Table 7.2: 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

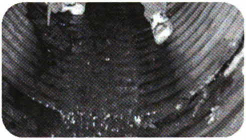


Figure 7.1: Big Hole and Corrosion in the Invert of the Culvert 25001273A01

Figure 7.2: 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 6.4; minor cracks and major spalling was found inside the culvert structure. Moderate misalignment of the culvert was found as shown in the figure 7.3. 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 7.3.

Table 7.3: 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

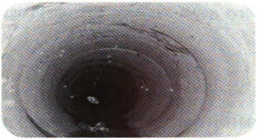


Figure 7.3: Misalignment of the Culvert

Figure 7.4: 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 7.5. The culvert headwall and the barrel were partially broken as shown in figure 7.6. 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 7.7. Overall the culvert deterioration was very significant. The condition rating system for this culvert is as shown in the Table 7.4.

Table 7.4: 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

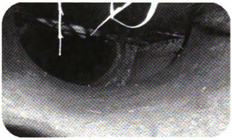


Figure 7.5: Significant Misalignment of the Culvert Structure

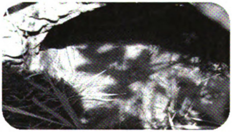


Figure 7.6: Vegetation and Heavy Spalling in the Headwall

Figure 7.7: Cracks on the Roadway Surface

The culvert 31000131B03 (Slab - 8' opening, 7' rise; Concrete) located in Shiawassee County is also about 65 years old. Age deterioration is 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 side walls of the culvert as shown in figure 7.8; Minor cracks on the roadway due to infiltration. The headwall and wingwall has hairline cracks and the embankment is eroded. The footings are in good condition. The condition rating system for this culvert is as shown in the Table 7.5.

Table 7.5: Condition Rating for Culvert 31000131B03

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 7.8: Condition of Culvert 31000131B04

The culvert structure 31000131B04 (24" CMP Circular) is totally failed. The pipe is completely closed on one side. Overall, the pipe is corroded inside and outside. The roadway has a pothole and moderate cracks due to culvert deterioration. The embankment is partially eroded. The culvert has no end treatment. The condition rating for this culvert is as shown in the Table 7.6.

Table 7.6: 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 7.9: Corrosion on the Outside Surface of the CMP

Figure 7.10: Total Failure of the Culvert End

The culvert 31000131B05 (Slab – 8' opening and 7' rise) is located in Shiawassee County and is also about 65 years old. This culvert is deteriorated, but functioning normal. Moderate deposition of soil sediments over the invert, headwall and wingwall is 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 is heavily eroded. The condition of the footing looks good. Overall, the culvert is in poor condition. The condition rating for this culvert is as shown in the Table 7.7.

Table 7.7: 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 7.11: 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 – Green, Yellow and Red.

The calculation of relative weights of the different components affecting the performance of the culvert is explained in Chapter 6 and is as shown in Table 7.8. The performance score is calculated by multiplying the condition rating of each component with their respective relative weight and finally summing up all the vales. The performance score for culvert 25001273A01 is as shown below:

Table 7.8: Performance Score Calculation for Culvert 25001273A01

Culvert 25001273A01	Condition Rating	Relative weight	Performance Score
Condition of the Invert	1	0.21115	0.21115
Condition of End Treatment	3	0.14175	0.42525
Condition of Overall Culvert	2	0.39280	0.78560
Condition of Roadway	5	0.05901	0.29505
Condition of Embankment	3	0.06378	0.19134
Condition of Footing	5	0.13118	0.65590
Final Performance Score			**2.56000**

The final performance score for culvert 25001273A01 is 2.56. 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 7.9.

Table 7.9: Performance Score Calculation and Zoning for Inspected Culverts

Culvert Identification Number	Performance Score	Zone
31000131B01	2.884	Yellow
31000131B02	2.120	Red
31000131B03	3.800	Green
31000131B04	2.430	Red
31000131B05	2.470	Red

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 red 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 7.10 and 7.11.

Table 7.10: ACA Performance Score Calculation for Culvert 31000131B02

Culvert 31000131B02	ACA Condition Rating	ACA Relative Weight	ACA Performance Score
Cracking	2	0.3170	0.6340
Scouring	5	0.1703	0.8515
Settlement	2	0.1563	0.3126
Joint Problem	1	0.1521	0.1521
Misalignment	1	0.1348	0.1348
Concrete Surface	4	0.0690	0.2760
Final Performance Score			**2.361**

Table 7.11: 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			**2.5133**

7.3 Summary:

This phase of 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 an 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 (Safe), Yellow (Intermediate) and Red (Danger) zones. The culverts under red zone were further investigated to calculate the ACA condition rating and performance score. The summary of the investigation is as shown in the Table 7.12.

Table 7.12: Summary of the Pilot Field Study

Culvert No.	County	Shape	Material	Span	BCA Score	Zone	ACA Score	Year Built
25001273A01	Ingham	Circular	CMP	48"	2.560	Yellow	-	-
31000131B01	Shiawassee	Circular	Concrete	24"	2.884	Yellow	-	1931
31000131B02	Shiawassee	Circular	Concrete	24"	2.120	Red	2.361	1931
31000131B03	Shiawassee	Slab	Concrete	96"	3.800	Green	-	1931
31000131B04	Shiawassee	Circular	CMP	24"	2.430	Red	0	1931
31000131B05	Shiawassee	Slab	Concrete	96"	2.470	Red	2.513	1931

CHAPTER 8

CONCLUSION AND RECOMMENDATIONS

8.1 Research Summary

The main goal of this research was to develop a model for culvert inventory and inspection, as a part of the asset management strategy. Asset inventory and inspection model is the foundation in developing any management strategy for preserving our deteriorating infrastructure. This research studied the state of practice culvert asset management in USA and Canada, developed a model for culvert inventory and inspection, and validated the model by conducting pilot field study.

The culverts throughout the nation are facing significant performance challenges as they are nearing the end of their design life. Different types of culverts have different life expectancies; concrete culverts have about 70 – 100 years, CMP and plastic culverts have about 50 years of design service life. These culverts are in need of special attention in terms of proactive or preventive asset management approach. The DOT's throughout the nation do not have any protocols to track and inspect these deteriorating culverts. This would increase the field problems and safety risk. The developed models in the form of condition rating system and performance calculator will assist the state and local agencies in making proper decisions and implementing a good asset management program.

The field study conducted in Lansing, Michigan successfully identified six culverts using a unique identification number and assessed the condition of the culverts. Three out of six culverts inspected were in danger zone. The common problems identified were misalignment, joint failure, cracking, spalling, corrosion, scouring, age deterioration, erosion of the embankments, potholes or cracks on roadway and heavy vegetation or settlement problems. The DOT's can use this model in categorizing the culverts in different zones and develop short and long term plans for each zone.

8.2 Recommendations:

This section gives recommendations for DOT's in developing an effective culvert asset management strategy.

- Establishment of asset management team for culvert structures – The successful implementation of culvert asset management requires all divisions in the agency to participate in the program. The establishment of asset management team would result in better co-ordination of financial, strategic planning, information technology and asset management activities, and having wider accountability for achieving and reviewing asset management goals and objectives.
- Identify the existing assets – The DOT's using the inventory model should track all the culverts nationwide. They can link all the state inventories into a one nation wide culvert database and share information across the states. This would help the federal to make decisions regarding budget allocations based on culvert information.
- Condition assessment and performance monitoring – It is critical for agencies to have a good knowledge of the condition of their assets and how they are performing. They have to access the existing condition assessment practices based on environmental factors, asset factors, maintenance or failure history, and

agencies condition assessment objectives and policies. The impact of time, cost and risk issues on condition assessment goals and objectives must be identified to investigate alternative options.

- Identification of failure modes – The agencies by analyzing how the asset can fail, will help in developing maintenance plans, planning for emergency budget and investigative activities to embrace the uncertainties associated with sudden failure of culvert structures.
- Maintenance planning – Developing an maintenance plan like developing failure data or reports, maintenance documents, identifying those failures that cannot be prevented, predicted or delayed and develop renewal or rehabilitation strategies to improve the performance of the culverts
- Develop a decision support system – Development of a decision support system would integrate the inventory, inspection, failure modes, maintenance planning and repair or rehabilitation information and give optimized management plans to preserve the culverts.

8.3 Limitations

This study though gives a practical solution for a practical problem; it does not take two important factors – time and cost into consideration. These factors can have considerable impact on the implementation of the models by DOT's. Good data for developing condition rating system was difficult to collect. Therefore, the DOT's by recording good performance or maintenance standards can have a better condition rating system. In performance calculator, the calculation of relative weights for BCA and ACA using AHP, depends upon the researchers knowledge and experience in culvert inspection and maintenance. So, the DOT's can have better relative weights for the culvert components and problems by having a culvert expert calculating it. The field pilot study on six culverts was insufficient in understanding the type and magnitude of field problems. More the culverts are studied; the better model can be developed.

8.4 Areas of Future Research

There are different possible areas of future research associated with this study. This study creates a platform for different research related to culvert asset management. Few of the research topics related to this study are as follows:

Development of an Asset Management Model for Culvert Repair and Rehabilitation

This study on inventory and inspection of culverts indicated a high rate of deteriorating culverts nationwide. Once the state and local agencies have sufficient knowledge of ownership of their assets and their current condition, there is a need for renewal, rehabilitation and repair of these culverts. By developing an asset management model for renewal and rehabilitation incorporating trenchless technology methods, various complex issues after condition assessment can be addressed. Also, determining the most cost effective planned and unplanned maintenance methods is a key to advanced culvert asset management.

Determination of Culvert Failure Modes for Effective Asset Management Maintenance Planning

As culvert failures are sudden, it is very important for an agency to know how a culvert may fail to deliver required level of service. The understanding of these failure modes would contribute in developing deterioration curves, failure timing, risk assessment and treatment options for effective culvert maintenance.

Development of an Asset Management Framework using Artificial Neural Networks

An artificial neural network is an effective tool in the area of decision making as it is based on knowledge expertise and experience. It can be used to manage, analyze and optimize the flow of information from various components or departments of an asset management framework. The agencies by implementing a decision support system like artificial neural networks would benefit in having a cost effective, time saving, and optimized flow of information. This helps in making better decisions at all levels of the organization.

APPENDIX -1

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.

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

- ☐ Yes
- ☐ No
- ☐ Don't Know

Drainage Infrastructure

- ☐ Yes
- ☐ No
- ☐ 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

- ☐ Yes
- ☐ No
- ☐ Don't Know

Drainage Infrastructure

- ☐ Yes
- ☐ No
- ☐ 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/ rehabilitation 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 -2

SURVEY RAW DATA

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 metres.
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

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

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 -3

CULVERT INVENTORY PROTOCOL

A. GENERAL

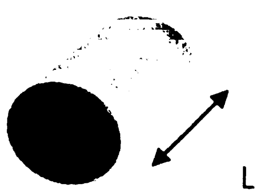
1. Date of Inventory:	2. Name of the Person:
3. State Code:	4. Country Code:
5: Place Code:	**6. Inventory Code:**
7. Functional Classification:	8. Mile Marker
9. Year Built	10. Latitude
11. Longitude	12. Maintenance Responsibility:
13. ADT:	14. Approach Roadway Width:
15. Culvert Marker:	

B. STRUCTURAL

Barrel

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

* 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:

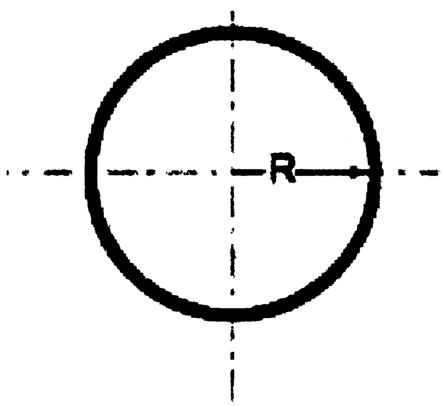
23. R_t = ____________________

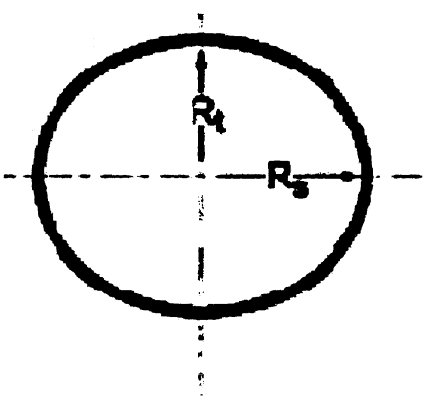
24. R_c = ____________________

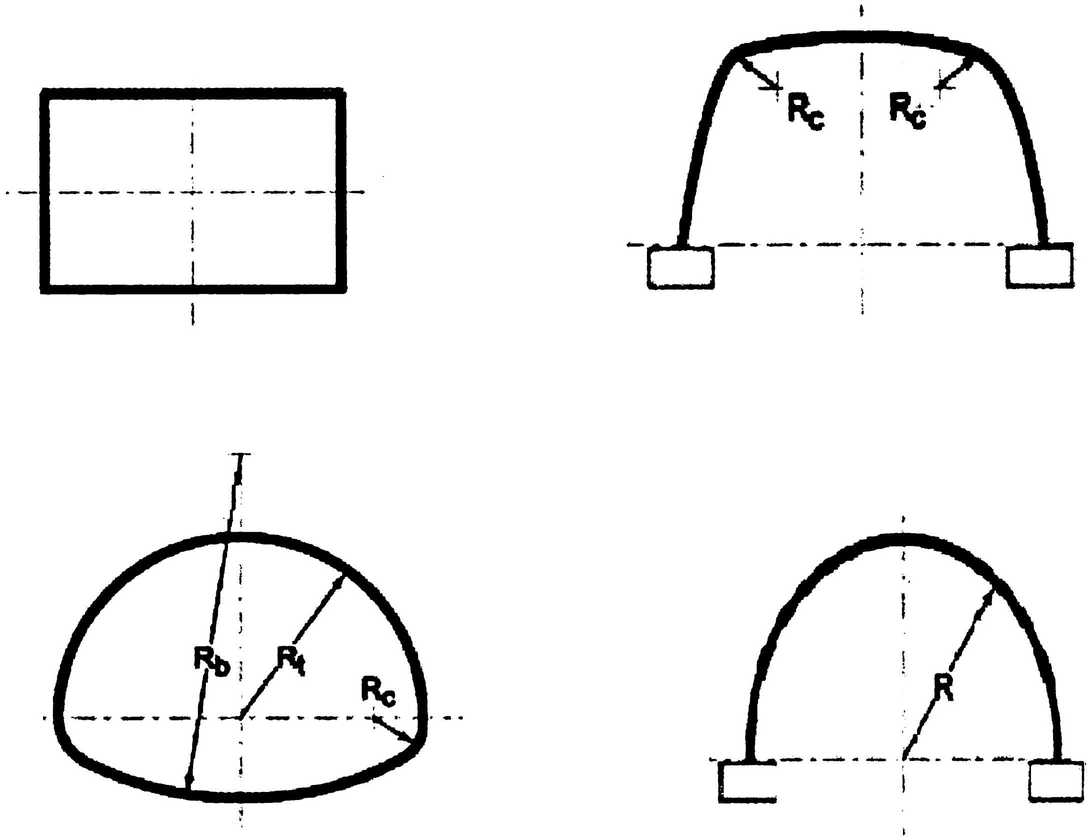
25. R_s = ____________________

26. R_b = ____________________

27. R = ____________________

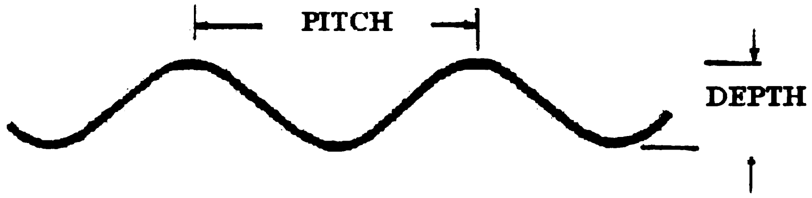






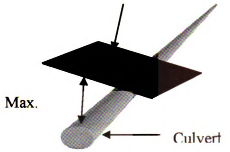
Metal Pipes

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



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

(See figure below)



C. 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:

D. HYDRAULIC

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:

E. SAFETY ITEM

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

F. RENEWAL or REHABILITATION

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

APPENDIX -4

CULVERT INVENTORY MANUAL

Item 1. Date of Inventory: (6 digits)

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

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:

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 Micronesa 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:

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
014	Cass
015	Charlevoix
016	Cheboygan
017	Chippewa
018	Clare
019	Clinton
020	Crawford
021	Delta
022	Dickinson
023	Eaton
024	Emmet
025	Genesee
026	Gladwin
027	Gogebic
028	Grand Traverse
029	Gratio
030	Hillsdale
031	Houghton
032	Huron
033	Ingham
034	Ionia
035	Iosca
036	Iron
049	Mackinac
050	Macomb
051	Manistee
052	Marquette
053	Mason
054	Mecosta
055	Menominee
056	Midland
057	Missaukee
058	Monroe
059	Montcalm
060	Montmorency
061	Muskegon
062	Newaygo
063	Oakland
064	Oceana
065	Ogemaw
066	Ontonagon
067	Osceola
068	Oscoda
069	Otsego
070	Ottawa
071	Presque Isle
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

- **Level of Service (1 digit)** – Enter the designated level of service 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"

So, Inventory Code is 11000904

Item 7. Functional Classification: (2 digit)

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
	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 digit)

Print the year, the culvert was built as follows:

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

Item 10. Latitude: (8 digits)

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

Determine the latitude of each in degrees, minutes, and seconds to the nearest hundredth of a second. The leading zero can be added where ever necessary. The point of coordinate may be the invert of the culvert or any suitable point in the direction of inventory.

Ex:

Latitude	***Code***
81 degrees 10 minutes 10.52 seconds	**81101052**
9 degrees 02 minutes 9.30 seconds	**09020930**

Item 11. Longitude: (8 digits)

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

Determine the longitude of each in degrees, minutes and seconds to the nearest hundredth of a second. A leading zero shall be coded where ever 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 35.40 seconds	**19203540**
7 degrees 10 minutes 45.00 seconds	**07104500**

Item 12. Maintenance Responsibility: (2 digit)

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 Bureau of fish and wildlife is incharge of culvert inventory, then code "**15**"

Item 13. Average Daily Traffic (ADT): (6 digit)

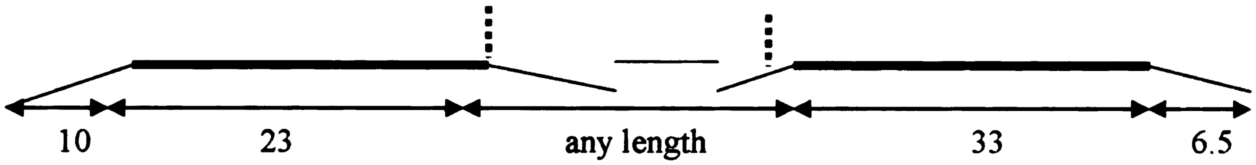
Code the average daily traffic volume (over the culvert) for the inventory route. The ADT coded should be most recent ADT counts available.

Ex:

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

Item 14. Approach Roadway Width: (4 digit)

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



All measurements in feet

Ex:
So, 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.

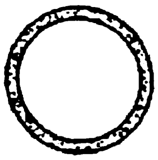
Code	Type
01	Wood Post
02	Metal Post
03	Other type
00	No Marker

Ex: If culvert marker type is wood, then code "**01**"

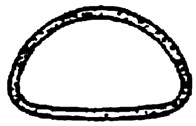
Item 16. Barrel Shape: (2 digits)

Code the shape of the culvert using the list below:

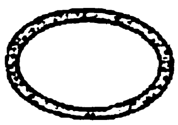
Code	**Type**
01	Circular
02	Pipe Arch
03	Horizontal Ellipse
04	Vertical Ellipse
05	Rectangular
06	Slab or 3 - sided
07	Arch



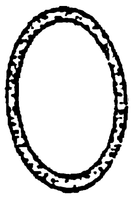
Circular Culvert



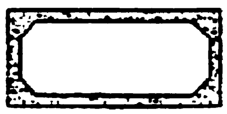
Pipe Arch



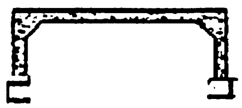
Horizontal Ellipse



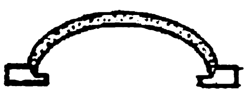
Vertical Ellipse



Rectangular



Slab Culvert



Arch

Ex: 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 Asbuilt 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**"

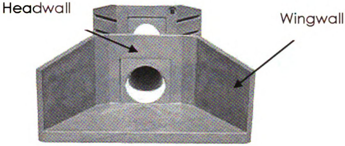
Note: Procedure to fill Items 19 to 31 is given on the Inventory Sheet

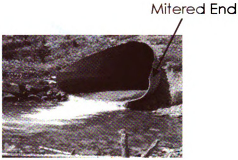
Item 32. Type of End Treatment: (2 digits)

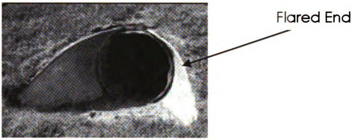
Code the type of end treatment at the inverts:

Code	Type
10	Projecting
11	Mitered
12	Pipe End Section (Flared or Terminal)
13	Headwall

14	Wingwall
15	Headwall and Wingwall



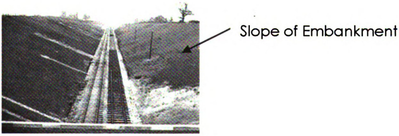


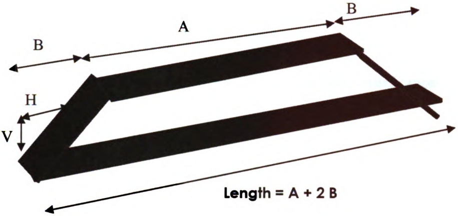


Item 33. Material: Refer Item 17

Item 35. Slope of Embankment:

Slope of embankment is determined as follows:

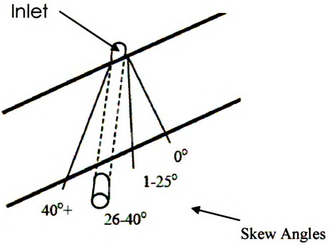




Slope of Embankment = $\frac{H}{V}$

Item 36. Skew Angle: (2 digits)

Stand at inlet, look across road perpendicular to road length and estimate degree of skew downslope.



Code	Skew Angle (degrees)
00	0
01	1 – 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
E 2	Gravel or Stone Road
F	Bituminous
G 1	Mixed Bituminous - combined base with surface under 7”
G 2	Mixed Bituminous - combined base with surface 7” or more
H 1	Bituminous Penetration - combined base under 7”
H 2	Bituminous Penetration - combined penetration 7” or more
I	Bituminous Concrete – sheet asphalt or rock asphalt road
J	Portland Cement Concrete Road
K	Brick Road
L	Block Road
Z	Water Macadam Road
Z 1	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. "n" value is determined by inspecting the culvert and comparing them to the values given below:

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	0.022 – 0.027

	Annular	
	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
Corrugated Polyethylene	Smooth	0.009 – 0.015
Corrugated Polyethylene	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 Asbuilt 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

Rip Rap

Loffelstein Blocks

Gabions

Earth
Reinforcement

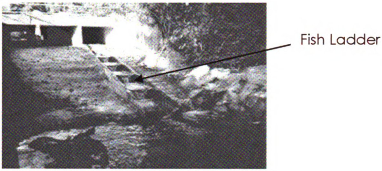
Concrete Paving of Earth Slopes

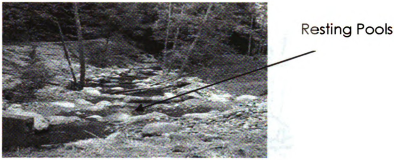
Item 47. Type of Fish Passage: (3 digits)

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

Baffle Wall





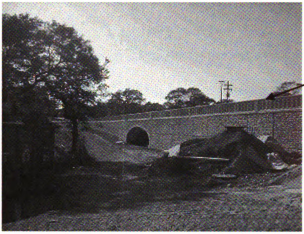
Item 48. pH of Water:

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



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 -5

CULVERT CONDITION ASSESSMENT PROTOCOL

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:

<table>
<tr><td>1. State Code:</td><td>2. County Code:</td><td>3. Place Code:</td></tr>
<tr><td colspan="2">4. Culvert Identification Number:</td><td>5. Year Built:</td></tr>
<tr><td>6. Date of Inspection:</td><td colspan="2">7. Inspector's Name:</td></tr>
<tr><td colspan="3">8. Maintenance Responsibility:</td></tr>
</table>

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)

☐

☐

☐

F. Comments:	**G. Recommendations:**

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 rehabilitation 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 rehabilitation 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 rehabilitation of the culvert

% Performance Improvement

APPENDIX -6

CULVERT CONDITION ASSESSMENT MANUAL

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:

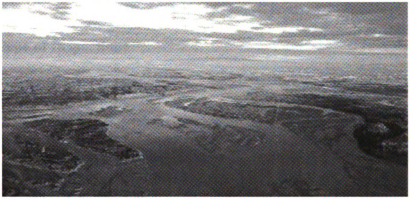
Code the time of culvert inspection

Item 12. Type of Stream: (2 digits)

Code the type of stream entering into the culvert as follows:

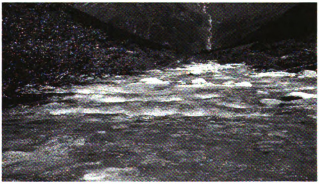
Code	Type of Stream
10	Braided Stream
11	Straight Stream
12	Meandering Stream
13	Other
00	No Stream

Braided streams consists of multiple and interlacing channels. They are wide, and the banks are poorly defined and unstable.



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



Straight Stream

Meandering streams consists of alternating bends of an S-shape as shown in the figure.

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 atleast 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

Animals in culverts

Slippery surface

Posted warning

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, 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, minor rotation

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

Calculation of Performance Factor

Rating system for performance calculation:

1 – Equal Importance
2 – Moderate Importance
3 – Intermediate Importance
4 – Strong Importance
5 – Extreme Importance

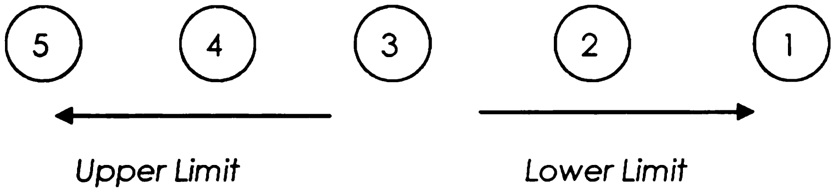
	Culver t	*Invert*	*End Treat*	*Footing*	*Roadway*	*Embankment*
Culverts	1	3	3	3	5	5
Inverts	0.2	1	2	2	4	4
End Treat	0.333	0.5	1	2	2	2
Footing	0.333	0.5	0.5	1	4	2
Roadway	0.2	0.25	0.5	0.25	1	1
Embankment	0.2	0.25	0.5	0.5	1	1
	2.266	5.5	7.5	8.75	17	15

	Culvert	*Invert*	*End Treat*	*Footing*	*Roadway*	*Embankment*
Culverts	0.4413	0.5454	0.4000	0.3428	0.2941	0.3333
Inverts	0.0882	0.1818	0.2666	0.2285	0.2352	0.2666
End Treat	0.1469	0.0909	0.1333	0.2285	0.1176	0.1333
Footing	0.1469	0.0909	0.0666	0.1142	0.2352	0.1333
Roadway	0.0882	0.0454	0.0666	0.0285	0.0588	0.0666
Embankment	0.0882	0.0454	0.0666	0.0571	0.0588	0.0666

Relative weights obtained from above matrix:

Type	***Relative Weights***
Overall Culvert Condition	0.39280
Condition of Inverts	0.21115
Condition of End Treat.	0.14175
Condition of Footings	0.13118
Condition of Roadway	0.05901
Condition of Embankment	0.06378

Scale Range



<u>Final Performance Score for categorizing the culverts into zones</u>

Performance Score	***Zone***	***Zone Meaning***
3.5 +	Green	Safe
3.5 – 2.5	Yellow	Intermediate Stage
> **2.5**	Red	Danger

Advanced Condition Assessment for Culverts in Red Zone

Metal Culverts

- 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" and ponding of water is less than or equal to 2"

D – Significant misalignment – offset more than ½" and less than 2" and ponding of water is greater than 2" and less than 5"

E – Significant misalignment – offset greater than 2" and 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 bolt holes

C – Minor cracking, evidence of backfill infiltration, minor rusting around bolts, more than 3 missing bolts in a row

D – Moderate cracking at bolt holes, 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 bedload of silt, sand, or gravel and less devoid of floating debris

F – Large boulders and large rock fragments carried as a bedload

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")

C – Moderate bed scour or bank erosion (6" – 2')

D – Significant bed scours and bank erosion (> 2')

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.

	Alignment	Settlement	Vegetation	Seam	Shape	Corrosion	Scouring
Alignment	1	3	3	1	1	3	3
Settlement	0.333	1	3	1	1	1	1
Vegetatio n	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

	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

	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 hair line cracks with/without minor delaminations or spalling (depth less than 0.25 inches)

D – Major delaminations or spalling exposing reinforcing steel (depth between 0.25 – 0.5 inches)

E – Extensive cracking, spalling and/or delaminations (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")

C – Moderate scouring at the ends and/or inside the culvert (depth between 6" – 2')

D – Significant scouring of the concrete bed (> 2')

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") and allowing backfill to infiltrate

E – Significant infiltration or exfiltration due to joint opening (greater than 3")

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" and ponding of water is less than or equal to 2"

D – Significant misalignment – offset more than ½" and less than 2" and ponding of water is greater than 2" and less than 5"

E – Significant misalignment – offset greater than 2" and ponding of water greater than 5"

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 inches, light honeycombing or efflorescence (less than 5% of the surface area)

C – Moderate discoloration; minor age deterioration; medium scaling (1/4" – ½") and/or honeycombing or efflorescence (5 – 15% of the surface area)

D – Age deterioration and discoloration is significant; major scaling (½" – 1"); 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

	Cracking	Scouring	Settlement	Joint Opening	Mis alignment	Concrete Surface
Cracking	1	3	3	1	1	3
Scouring	0.333	1	1	1	1	3
Settlement	0.333	0.5	1	1	1	3
Joint Opening	0.5	0.5	0.5	1	1	3
Misalignment	0.5	0.5	0.5	0.5	1	3
Concrete Surface	0.333	0.333	0.333	0.333	0.333	1

	Cracking	Scouring	Settlement	Joint Opening	Mis alignment	Concrete Surface
Cracking	0.3330	0.5140	0.4737	0.2068	0.1875	0.1875
Scouring	0.1110	0.1714	0.1579	0.2068	0.1875	0.1875
Settlement	0.1110	0.0857	0.1579	0.2068	0.1875	0.1875
Joint Opening	0.1660	0.0857	0.0789	0.2068	0.1875	0.1875
Misalignment	0.1660	0.0857	0.0789	0.1034	0.1875	0.1875
Concrete Surface	0.1110	0.0570	0.0525	0.0688	0.0624	0.0625

	Relative Weight
Cracking	0.3170
Scouring	0.1703
Settlement	0.1563
Joint Opening	0.1521
Misalignment	0.1348
Concrete Surface	0.0690

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" and ponding of water is less than or equal to 2"

D – Significant misalignment – offset more than ½" and less than 2" and ponding of water is greater than 2” and less than 5”

E – Significant misalignment – offset greater than 2” and ponding of water greater than 5”

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”)

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”); 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”) and possible infiltration

C – Moderate offset at the seam (between ½” – 2”) and minor infiltration or exfiltration

D – Significant offset at the seam (between 2” – 4”) and moderate infiltration or exfiltration

E – Severe offset at the seam (> 4”) 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") throughout the culvert material

D – Significant scour holes (between 1"- 2") or perforations at the invert

E – Severe scour holes (>2") 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"; width less than ¼") in few locations and/or hairline cracking

C – Minor splits (greater than 3" but less than 6"; width between ¼" – ½") in few Locations and minor cracking at crown or any location

D – Major Splits (greater than 6"; width greater than ½") 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

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