# USE OF TRENCHLESS TECHNOLOGIES FOR A COMPREHENSIVE ASSET MANAGEMENT OF CULVERTS AND DRAINAGE STRUCTURES

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16. Abstract

DOT's and cities in the US are facing severe and rising needs of renewing heavily deteriorated infrastructure. Further challenges for DOT's are the wide geospatial distribution of infrastructure assets and environmental exposure. While the challenge is well understood, appreciated and addressed, budget allocations and resources limitations represent a major barrier to a comprehensive asset management program. Culverts have the peculiarity of being characterized as both buried pipes in small diameters with no access and worker entry and larger ones with possibility of manual inspection and repair/renewal. As such, asset management procedures for culverts are a complex issue, and can benefit a great deal from an optimal asset management program that incorporates new trenchless technologies. Trenchless technologies are not disruptive to transportation systems and provide safer construction operations for both workers and the general public. If they are used at appropriate application, they provide a new design life to existing culverts and drainage structures that may double or triple the original design life of these assets. However, trenchless technologies are many and some of these methods are new, and while viable, have little field performance history in culverts and transportation systems. Each method has its own capabilities and limitations, and can be applied in certain existing conditions to be effective. Lacking is a comprehensive multi-scale engineering study that would be conducted for decision making at upper management level. Therefore, this project provides a comprehensive study and decision making procedures for asset management using trenchless technologies to address the construction, renewal, renovation, and inspection of culverts and drainage infrastructures.

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# EXECUTIVE SUMMARY

There are many good textbooks and manuals that describe renewal techniques for sanitary sewers, and many of the described techniques are suitable for the renewal of culverts and storm sewers. However, the literature is lacking in detailed guidance for those in search of information on renewal techniques specifically for culverts and storm sewers. The purpose of this report is to provide a resource for DOT's, design engineers, government agencies, consultants and others that are not familiar with or need a refresher course on culvert or storm sewer renewals.

Many drainage structures consist of pipes, manholes and other systems with pipe sizes in the 8 – 96 in. range. Renewal of drainage structures such as this is essentially the same as sanitary sewer renewal. Several manuals, textbooks and publications discuss these renewal techniques (See References 51, 75 & 76), and authors agreed that this report need not cover this territory again. In general, this report will cover drainage structures crossing under transportation systems (roads, highways, airports, railroads, canals, etc.).

However, there are grey areas. For example, what about a culvert passing under a school or playground? Renewal of this culvert would be the same as if it passed under a highway. In addition, what about open-ended drainage structures? As a result the authors decided to include certain drainage structures and include the words "drainage structures" in the title.

## SCOPE OF THE REPORT

The scope of this report is the trenchless renewal of culverts and drainage structures with a diameter or equivalent diameter range of 12 to 144 inches. The culverts and drainage structures must have at least one open end with any renewal proceeding from the open end to the first structure from the open end.

This scope allows the inclusion of drainage structures that have an open entrance or discharge. Any renewal processes described will be applicable from the open end to the first structure. From that point on, the drainage structure becomes an enclosed system, and renewal processes for enclosed systems are defined in other publications.

Some of the renewal processes described in this report have technical envelopes that go outside of this scope. For example, some spray-on techniques have no practical upper size limit. For some processes it doesn't matter whether the culvert or drainage structure is "open-ended." All these processes, technical envelopes and capabilities of trenchless technologies will be covered in detail in CHAPTER 3.

The most common types of culvert materials are concrete, plastic and metal. Concrete culverts are available in almost any size, certainly the size range within the scope of this report, and many shapes. Typical shapes are round, box, arch and elliptical. Plastic culverts are round and are generally manufactured from high-density polyethylene (HDPE) or polyvinyl chloride (PVC) and are available in either smooth or profile wall designs. Metal culverts are also available in many sizes and shapes, including round, box, arch and elliptical. Although the most common type is corrugated steel pipe, corrugated aluminum pipe can also be used.

Practically any material available for pipes or conduits has been used for culvert construction. However, for a broad range of applications and for a large number of culverts, concrete, plastic and steel continue to be the most widely used and cost-effective.

Culverts consist of an entrance, barrel and outlet. For noncircular shapes, size is described by culvert rise and culvert span. For circular culverts, size is expressed as culvert diameter.

Following are the major objectives and tasks discussed in this report.

## RESEARCH OBJECTIVES

The main objective of this project is to provide a comprehensive study and decision making procedures for the selection of appropriate trenchless technology methods for construction, renewal, renovation (collectively called renewal), and maintenance of culverts and drainage infrastructures. Other objectives of this research follow:

a) Review various geo-environmental and mechanical factors affecting the deterioration of culverts and the selection of appropriate trenchless technology methods.

b) Develop of a database of trenchless technology methods through literature review and survey of DOTs; methods already used in culvert structure and history of their performance.

c) Through industry survey and applications of trenchless technologies in other areas, such as municipal applications and sewer and water markets, an expansion of the above database is proposed with the use of trenchless technologies that have potential for renewal of culvert structures and have been utilized. Standard testing data will be considered as well as all other information that manufacturers can provide. Available academic research and third party testing will be included to come up with a comprehensive list of these technologies.

d) For each of the technologies included in the database, information will be compiled on range of application, diameter restrictions, type and geometry of culvert which they can be applied, diameter and/or cross sectional reduction, structural capability, hydraulic analysis (roughness factor), construction requirements, design life, life-cycle-cost, chemical (corrosion) and mechanical properties, maintenance issues and requirements, and other important parameters specific to the needs of MDOT, ODOT and other Midwestern states. All this information will be verified through multiple sources.

e) A specific review, inspection and maintenance requirements of renewed culverts (such as how and what to inspect) will be carried. Each trenchless technology will require a specific method of inspection. Therefore, an inspection and asset management methodology for trenchless renewal of culverts will be developed.

f) Modifications will be provided to buried pipes technologies to be implemented on culverts with emphasis on trenchless technologies.

g) An integration of MDOT and ODOT asset management computerized system and the findings of this report will be carried. The final compilation will help MDOT and ODOT engineers to select the best technologies given the culvert description and its condition, and will provide them with risks, performance and cost analyses as described previously.

h) Educational programs will be offered in terms of two workshops for MDOT and ODOT engineers to present the results of this research project and train them in the use of new asset management system using trenchless technologies.

i) Publishes and presentations will be carried at the TRB national convention, major professional and trade conferences, as well at peer-reviewed journals such as ASCE Journal of Transportation Engineering (JTE).

## RESEARCH TASKS

In order to address objectives the following tasks were accomplished:

a) Review existing literature for best practices on drainage infrastructure and culvert asset management.

b) Review factors affecting culvert deteriorations and the selection of appropriate trenchless technology methods.

c) Review and survey existing trenchless technology methods with potential use for construction, renewal, renovation and inspection of culverts and drainage infrastructures, and identify capabilities and limitations of each of these methods.

d) Identify inspection, asset management, and maintenance requirements of culverts and drainage infrastructures using trenchless technology methods.

e) Determine modification requirements in existing trenchless technologies to be used in culverts and drainage structures.

f) Collaborate with MDOT and ODOT to establish a database and decision support system for selection of appropriate trenchless technology methods.

g) Develop course modules for culvert asset management using trenchless technologies, comprehensive engineering and management procedures. Offer two workshops for MDOT and ODOT personnel. This task also includes technology transfer through paper publications and presentations at TRB, nationally and regional conferences.

# CHAPTER 1
# LITERATURE REVIEW

## 1.1 Introduction

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

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

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

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

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

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

**Location** – Actual location of the asset as denoted using a linear referencing system or GPR coordinates.

**Physical Attributes** – Description of the considered assets that can include: material type, size, length, etc.

**Condition** – Condition assessment can be different from one asset to another according to set performance criteria. The data can be qualitative and generic (e.g. good, bad, etc.) or detailed and/or quantitative in accordance to established practices and standards (e.g. condition or performance index).

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

## 1.2 GASB – 34

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

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

## 1.3 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*

## 1.4 Goals and Principles of Asset Management (NCHRP, 2002)

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

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

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

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

## 1.5 Asset Management Framework and Strategy (FHWA, 2000)

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

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

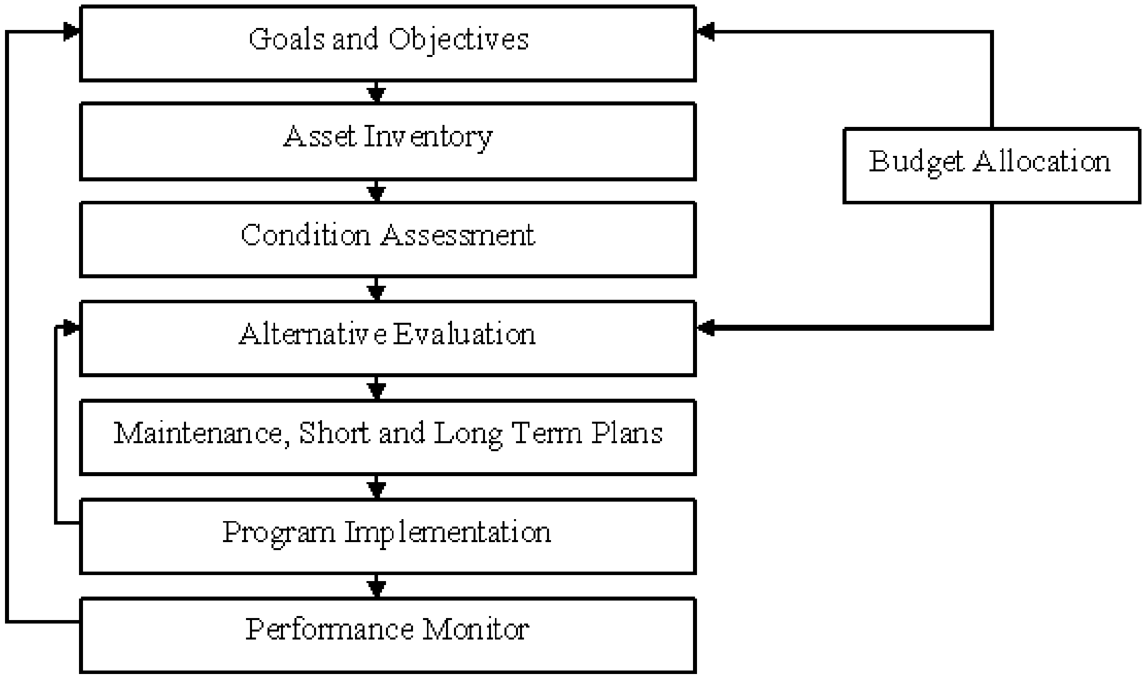


Figure 1-1 Generic Asset Management Framework

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

An asset management strategy focuses on maintenance practices associated with the component and the function of that asset. The ingredients of the strategy attempts to answer the questions listed in Table 1-1 (FHWA, 2000).

Table 1-1 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 |

## 1.6 Culvert Asset Management

Culvert asset management provides the ability to show how, when, and why culvert resources were or are committed. Transportation officials are highly accountable for all transportation assets. The 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's from asset management practices are (Perrin, 2004),

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

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

## 1.7 Culverts (Engineering Consideration)

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

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

## 1.8 Hydrology

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

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

- Peak Flow – peak flow refers to the maximum amount of water that will arrive and flow past a particular part of land. The peak flow is a major factor in the culvert design process. This value depends upon many topographic, geological, and environmental factors such as:

  - The size, shape and slope of drainage area
  - The rainfall intensity, storm duration, and rainfall distribution within the drainage area
  - Type of land use (open ground, paved, wooded, etc.)
  - The type of soil and its degree of saturation or imperviousness
  - Type of precipitation and ambient temperature
  - Existing flow if stream is present

## 1.9 Hydraulics

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

- Inlet Control

- Outlet Control

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

Figure 1-2 Culverts functioning as Inlet Control
(Source: Hydrocad Storm Water Modeling, 2008)

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

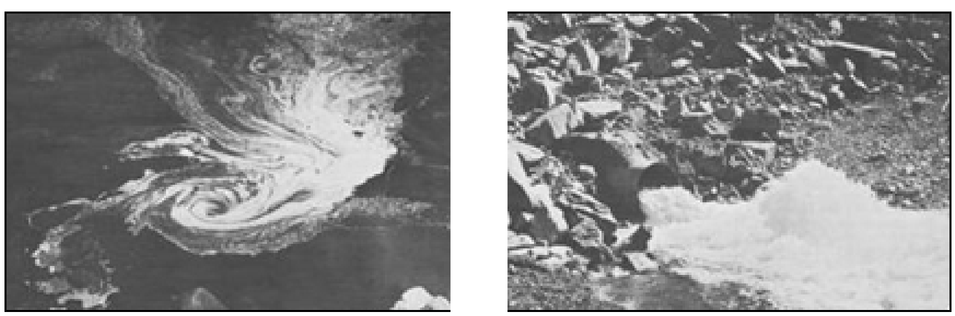

Figure 1-3 Culverts functioning as Outlet Control
(Source**:** Hydrocad Storm Water Modeling, 2008)

Table 1-2Comparisons between Inlet and Outlet Control
(Source: Haested Methods, 2006)

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

## 1.10 Types of Flow (FHWA, 2001)

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

Figure 1-4 Culvert Flowing under Pressure Flow
(Source: Eatonvillenews.net, 2008)

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

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

Where,

$F_r$ = Froude number	$y_h$ = Hydraulic depth

V = Average velocity of flow	g = Gravitational acceleration

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

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

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

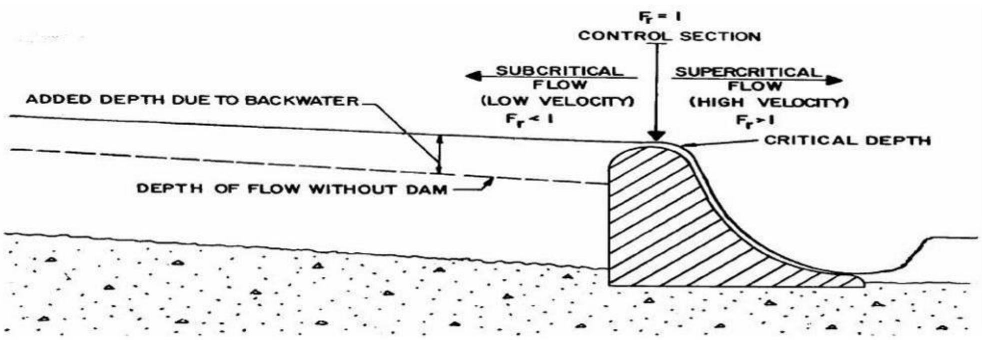


Figure 1-5 Flow Conditions for a Small Dam (Source: FHWA, 2001)

The same flow conditions as shown in Figure 1-5 occur in case of a partially full steep culvert. The critical depth would occur at the culvert inlet, subcritical flow could exist in the upstream channel, and supercritical flow would exist in the culvert barrel, as shown in Figure 1-6 .

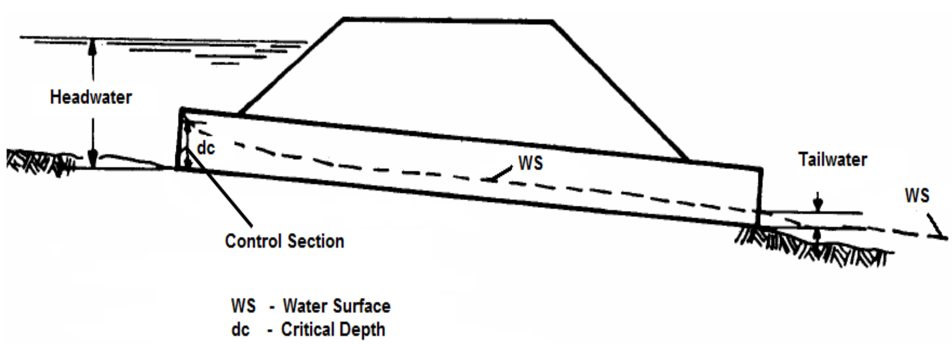


Figure 1-6 Typical Flow in a Partially Full Culvert (Source: FHWA, 2001)

## 1.11 Structural Aspects (FHWA, 1986)

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

Flexible culverts have less bending stiffness or bending strength on their own. As shown in the Figure 1-7, as vertical loads are applied a flexible culvert attempts to deflect. The vertical diameter decreases while the horizontal diameter increases. Soil pressures resist the increase in horizontal diameter.

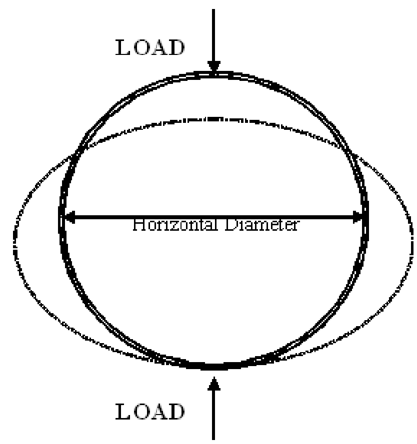


Figure 1-7 Deflection of Flexible Culverts (Source: FHWA, 1986)

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

*Rigid Culvert Behavior* – The load carrying capacity of rigid culverts is provided by the structural strength and from the surrounding earth. When vertical loads are applied to a rigid culvert pipe, zones of tension and compression are created as shown in Figure 1-8. Reinforcing steel is added to the tension zones to increase the tensile strength of concrete pipe. Shear stress in haunch area can be critical for heavily loaded rigid pipe on hard foundations. Since a rigid pipe is stiffer than the surrounding soil, it carries a substantial portion of the load.

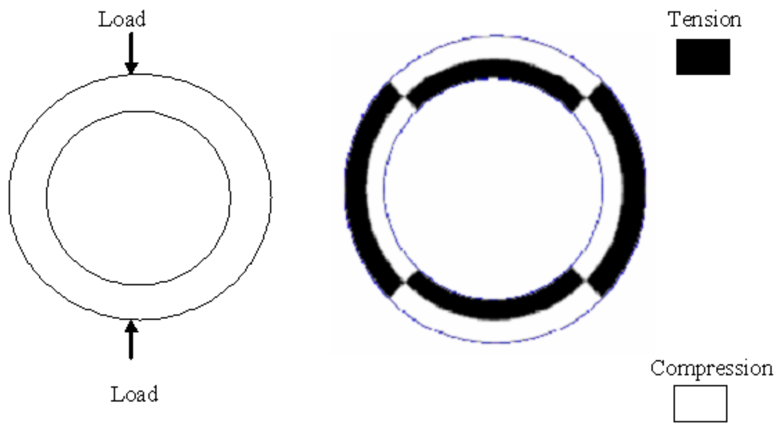


Figure 1-8 Zones of Tension and Compression in Rigid Pipes

### 1.11.1 Culvert Classification by Shapes

The common shapes of culverts used are,

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

Circular

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

Elliptical or Pipe Arch

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

Arches

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

Box Sections or Rectangular

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

Multiple Barrels

Multiple barrels (Figure 1-9) are used to obtain adequate hydraulic capacity under low embankments or for a wide waterway. Sometimes, they are prone to clogging as the area between the barrels tends to catch debris and sediment.

Figure 1-9 Multiple Barrel Culverts
(Source: American Concrete Industries, 2008)

## 1.12 Culvert Appurtenances and End Treatments (FHWA, 1986)

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

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

### 1.12.1 Headwalls

Headwalls (Figure 1-10) are entrance structures that protect the embankment from erosion and improve the hydraulic efficiency of the culvert. They provide embankment stability and protection from buoyancy. Properly designed, they shorten the required structure length and reduce maintenance damage. They also provide structural protection to inlets and outlets.

### 1.12.2 Wingwalls

Wingwalls (Figure 1-10) recess the inflow or outflow end of the culvert barrel. They anchor the pipe to prevent disjointing caused by excessive pressures and control erosion and scour resulting from excessive velocities and turbulences. They are generally used:

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


Figure 1-10 Culvert Showing Headwall and Wingwall

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

### 1.12.3 Energy Dissipaters

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

A *riprap basin* is riprapped floor constructed at the approximate depth of the scour. It is classified as either graded or ungraded. Graded riprap forms a flexible self-healing cover, while ungraded riprap is more rigid and cannot withstand movement of the stones. *Impact basins* dissipate energy through the impact of flowing water with various devices in the basin. One such device is a hook-type dissipater designed for culverts with low tailwater. A riprap basin is shown in Figure 1-11.

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

Figure 1-11 Riprap Basin to Protect Streambed and Stream Slope

## 1.12.4 Aprons

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

## 1.12.5 Fish Passage

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

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

### 1.12.6 Projecting

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

### 1.12.7 Mitered End

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

### 1.12.8 Skewed End

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

## 1.13 Chapter Summary

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

# CHAPTER 2
# FACTORS AFFECTING SERVICE LIFE OF CULVERTS

## 2.1 Introduction

Performance of a culvert is directly proportional to its remaining design service life (AASHTO, 1999). It is defined as the period of service without a need for major repairs. For corrugated metal pipes (CMP), this will normally be the period in years from installation until deterioration reaches the point of either perforation of any point on the culvert or some specified percent of metal loss. Reinforced concrete pipe service life is the period from its installation until reinforcing steel is exposed, or a crack signifying severe distress develops. Plastic pipe service life may be considered at an end when excessive cracking, perforation, or deflection has occurred.

Culverts require constant maintenance and can deteriorate for a number of reasons. A comprehensive study performed by the Water Research Center (WRc), concludes that the concept of measuring the rate of deterioration of sewers is unrealistic, and deterioration is more influenced by random events in a sewer life span. Examples of random events include a heavy rain storm or an excavation nearby. Distress and collapse of a culvert are the results of the complex interactions of various mechanisms that occur within and around the culvert. The impact of the deterioration depends upon the culvert size, complexity, topography, and service.

Culvert service life can also be affected by debris damage or erosion caused by major storm events and improper manufacturing, or handling of the culvert. Major factors influencing the performance or service life of a culvert are:

Durability factors
- Corrosion
  - Hydrogen sulfide
  - Chemical corrosion
  - External corrosion
- Abrasion
- Erosion

Loss of Structural Integrity
- Joint Separation
- Misalignment
- Seam Defects
  - Seam cracking
  - Longitudinal cracks
  - Transverse cracks

Environmental Factors
- Scaling
- Delamination

- Spalling
- Efflorescence
- Honeycombs
- Popouts

Hydraulic

- Insufficient capacity and Flooding

Operational Factors

- Roots
- Blockages debris
- Maintenance procedures

## 2.2 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.

### 2.2.1 Corrosion

Corrosion specifically refers to any process involving the deterioration or degradation of metal components. Metal culverts or reinforcement in concrete culverts corrode on contact with low $p^h$ value of water, acids, bases, salts, oils, and chemicals which act as an electrolyte, and metal acting as an anode, cathode, and conductor. As electrons move from the anode to the cathode, metal ions are released into solution, with characteristic pitting at the anode. The culvert will typically serve as both the anode and the cathode. Similar processes can occur to the cement in concrete pipe if subjected to highly alkaline soils or to other pipe materials if subjected to extremely harsh environments. Upon initiation, the corrosion process is self-sustaining, resulting in the formation of pits at the outer surface of the culvert, with a range of depths and widths. Different culvert materials have different characteristics in their reaction to corrosion. For instance, sulfate corrosion is produced as a result of sewer gases, excessive hydraulic flows, structural failures, leaks and infiltrations, and erosion. Furthermore, bacteria converts the sulfates to hydrogen sulfides which, when released into the culvert air space, become oxidized into sulfuric acid. The sulphuric acid is reactive to some pipe materials corroding it. Severe corrosion can jeopardize the structural integrity of a culvert and may lead to a collapse.

Corrosion is the process of returning metals to their native state of oxides or salts. Figure 2-1 shows corrosion in metal culvert. Corrosion of culverts may also occur in the presence of soils and water containing acids, alkalis, dissolved salts, and organic industrial wastes.

Figure 2-1 Corrosion in Culverts

The risk of interior corrosion of a culvert depends upon the susceptibility of the culvert material to corrosion and the amount of corrosive chemicals in the water. Interior culvert corrosion typically occurs from the formation and release of hydrogen sulfide. Hydrogen sulfide is formed in anaerobic conditions, such as debris piles, or pools caused by sagging lines. It is assumed that anaerobic conditions exist in open channel flow at the wetted perimeter, and therefore, a small amount of hydrogen sulfide is generated and some corrosion can occur if the conditions allow for release (ASCE, 1994). Hydrogen sulfide gas is released in turbulent conditions. Such conditions occur at culvert outlets, drop structures greater than 2ft, a change in slope, and during high water velocities.

Acidic soils or groundwater attack unprotected cementitious or metal culvert materials, whereas stray currents in the ground cause a galvanic corrosion with metal or metal reinforced culverts.

### 2.2.2 Abrasion

Abrasion is the gradual wearing away of the culvert wall due to the impingement of bedload and suspended material. Abrasion will almost always manifest itself first in the invert of the culvert. As with corrosion, abrasive potential is a function of several items, including culvert material, frequency and velocity of flow in the culvert, and composition of the 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.

Figure 2-2 Deterioration due to Abrasion (Caltrans, 2003)

By far, bedload is the leading cause of culvert abrasion. Critical factors in evaluating the abrasive potential of bedload material are the size, shape, and hardness of the bedload material and the velocity and frequency of flow in the culvert. Generally, flow velocities less than 1.5 m/s (5 ft/s) are not considered to be abrasive, even if bedload material is present. Velocities in excess of 4.5 m/s (15 ft/s), which carry a bedload, are considered to be very abrasive and some modifications to protect the culvert should be considered. To date, there has not been extensive testing conducted for velocities exceeding 4.5 m/s (15 ft/s), and extrapolation of existing test data to very high velocities is not recommended. Attempts to compare laboratory testing to field conditions to estimate the effects of bedload abrasion must be carefully considered. Designers should not use peak flow rate velocities in service life calculations.

It is very difficult to look at a given culvert material and provide an absolute determination of how it will be affected by bedload abrasion. Perhaps the most useful method of making a reasonable determination is to look at the various types of culvert materials and make relative comparisons. Tests performed on concrete pipe have generally shown excellent wear characteristics. Although high-velocity flow will induce abrasion regardless of the size of bedload particles, tests performed on concrete pipe have shown that cobble and larger sizes (over 75-mm (3-in.) diameter) will induce higher wear rates than sands and gravels. Larger rocks apparently impact with enough force to break away minute particles of the wall. The use of high-quality aggregate (i.e., aggregate that is harder than the anticipated bedload hardness) in the concrete mix can greatly enhance the wearability of the concrete. Likewise, manufacturing methods that lead to a denser concrete mix, such as roller compacted or spun concrete, or higher compressive strength concrete can exhibit increased wearability. Where velocities are known to be high, and a bedload is present, many entities recommend additional concrete cover over the reinforcing steel. The presence of a very high or very low pH environment will accelerate the abrasive effects of any bedload conditions.

Steel culverts are the most susceptible to the dual action of abrasion and corrosion, particularly where thinner walled pipes are used. Once the thin protective coating on a steel pipe is worn away, whether it is zinc or other substance, exposure to low resistivity and/or low pH environments can dramatically shorten the life of a steel culvert. Although aluminum culverts are occasionally specified to combat corrosion, plain aluminum is typically not recommended for abrasive environments since tests indicate that aluminum can abrade as much as three times the rate of steel. Abrasive effects are typically countered in metal pipes by the use of:

- Protective coatings,
- Invert paving
- Added metal thickness
- Or a combination of these measures.

Plastic culvert materials (both polyvinyl chloride and high-density polyethylene) exhibit good abrasion resistance. Since plastic is not subject to corrosion, it will not experience the dual action of corrosion and abrasion. Plastic pipes, like metal pipes, have relatively thin walls and thus the rate of wear must be carefully evaluated with the material thickness. The documented abrasive resisting capabilities of plastic pipe is primarily based upon tests using small aggregate sizes (gravels and sands) flowing at velocities in the range of 0.6 to 2.1 m/s (2 to 7 ft/s). The effects of large bedload particles (cobbles and larger) and/or high velocity flows are not well defined due to limited data. Additionally, due to their more recent emergence as a culvert product, the plastic pipes have generally not had rehabilitative strategies developed specifically for them. Some of the more popular current strategies (e.g., invert paving) are not effective with plastic pipes due to the smooth surface of the plastic and an inability to achieve a satisfactory bond.

### 2.2.3 Erosion

Erosion or scour at culvert ends can result from inadequate energy dissipation, headcutting that reaches a culvert, improper entrance or exit alignment and design, high watertable (above culvert level), frequent and high magnitude of hydraulic surcharge, and soil types (silts, silty fine sands, and fine sands). Regardless of the cause, the removal of structural backfill from around the culvert eliminates the ability for the pipe to support loading. Loss of side support will allow the sides of the culvert to move outward when loaded vertically, and collapse will likely occur once the culvert deformation exceeds 10 percent. Uneven loading of culverts because of joint displacement also accelerates the pipe deterioration process. Erosive effects at culvert ends or the erosive effects of piping may lead to the ultimate failure of the culvert and precautionary measures should be taken as a part of routine design practice.

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

## 2.3 Loss of Structural Integrity

Although generally unpredictable from a design standpoint, there are other physical factors besides corrosion and abrasion that can shorten the life of drainage culverts. The loss of structural integrity can sometimes be traced to a defect in the manufacture of the pipe, improper construction techniques or the effects of a large storm event. More commonly, though, the loss of structural integrity occurs over many years and is related to such factors as piping, seepage, soil movement, scour, and backfill soil loss. These processes can gradually reduce the culvert strength and make it susceptible to catastrophic events such as floods. The engineer is unable to predict when or how a particular drainage facility might be affected by one of these factors. Therefore, it is important to establish a program of routine inspections to identify the progression of a problem before damage to the roadway occurs.

Structural deterioration is hypothesized to be influenced by a set of installation and construction factors, including pipe design, pipe size, buried depth, and site factors such as soil type, moisture index and tree root intrusion (Tran et al. 2006). Structural defect failure mechanisms include cracks and fractures in the pipeline material that are caused by a change in the forces around a pipeline or a change in the ability of the pipe material to resist existing forces. The infiltration of groundwater through existing structural defects creates or increases the size of voids as the infiltrating water carries particles from the soil into the pipeline. The weakening of this soil makes the strata above the pipe vulnerable to surface collapse. The effects of infiltration on void formation are made worse by the process of exfiltration. Exfiltration occurs when water leaves the pipeline through structural defects during periods of hydraulic surcharge. Surcharge waste water can scour or loosen more fines at the perimeter of the voids. Common defects found in any culvert type are:

### 2.3.1 Joint Separation

Allowable joint separation depends upon the type of joint being used. Joints with an external sleeve (as used for most corrugated metal pipes and corrugated high-density polyethylene) can allow a limited amount of axial separation between abutted pipe ends since the external sleeve will typically maintain joint integrity and limit infiltration/ exfiltration. For bell-and-spigot-type joints, there is no allowable separation; instead, some minimum amount of overlap at the joint corresponding to the pipe diameter is usually specified. This minimum amount of overlap at the joint becomes particularly important for pipes installed on a curved alignment. While the portion of the pipe joint on the inside of the curve may have no problem with meeting the minimum overlap, most specifications will call special attention to that portion of the pipe on the outside of the curve and require specially manufactured curved or angled pipe sections if the minimum overlap cannot be attained. There can be numerous causes of joint separation or insufficient overlap, with the most common being inadequate quality control during construction. This can be due to uneven bedding, uneven or poorly compacted backfilling operations, or unexpected settlement. Joint problems are also common when culverts are installed under existing roadways by constructing half the width at a time. This usually is accomplished by closing half of the roadway width while the other half is still open to traffic. The half section is then constructed in an open trench operation. The same procedure is then repeated on the other half of the roadway. Adequate backfill compaction and alignment at the point where the two halves meet is very difficult and proper joining may not occur. In addition to problems related to construction, natural forces can lead to joint separation and/or inadequate overlap. Earthquakes and landslides can easily shift culvert positions as can frost heave. Pipes laid on steep slopes, particularly downdrains that are often laid on the surface of the slope, are subject to joint separation. Anchorage and/or higher strength joint connections are often specified.

Culverts should be inspected for movement after any major natural event that could result in a shifting of culvert position.

Figure 2-3 Culvert Pipe showing Cracks and Joint Separation

The main functions of culvert joints are to be watertight, durable, and resistant to root intrusion. Joint failures are due to leaks where pipe joints become separated or rubber ring is improperly sealed. Joint type is an issue because the type of joint will influence the susceptibility of the pipe to specific failures. A large part of joint problems may be due to the amount of flexibility and lateral constraint the joint provides, as well as the culvert joint's actual strength and its ability to resist corrosion.

### 2.3.2 Misalignment

Almost all of the problems that can cause joint separation can also lead to misalignment. Minor deviations from the planned alignment are not typically harmful. Minor amounts of deflection (or pull) at successive joints are occasionally planned into the design to create a curve in the alignment. Segmental construction, where portions of a single pipe run are constructed at separate times, will often lead to misalignment due to differing settlement rates and the difficulty in maintaining constant grade through the area of segment connection. For these reasons, it is generally preferable to construct an entire run of pipe in a single sequence.

### 2.3.3 Seam Defects

Seam defects are the result of poor manufacturing or improper handling. Defects of this type are typically caught prior to installation but, if undetected, may lead to culvert failure. Proper inspection during the construction phase, and obtaining pipe meeting material specifications, are necessary to limit these potential problems.

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

### 2.3.4 Seam cracking

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

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

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

### 2.3.5 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 2-4.

Figure 2-4 Longitudinal Crack in a Culvert Pipe
(Source: National Research Council Canada, 2006)

### 2.3.6 Transverse Cracks

Poor bedding, as shown in Figure 2-5, causes transverse cracks or circumferential cracks. Cracks occur across the bottom or crown of the pipe when it is supported at the ends of each section. This is the result of poor installation practices, such as not providing sufficient depth of suitable bedding material.

Figure 2-5 Transverse Cracks in a Culvert Pipe

## 2.4 Environmental Factors (Caltrans, 2003)

### 2.4.1 Scaling

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

Figure 2-6 Scaling exposed on Concrete Surface.
(Source: Photomac Construction industries, 2008)

### 2.4.2 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 2-7 Delamination on a Concrete Surface.
(Source: Concrete Restoration and Construction, 2007)

### 2.4.3 Spalling

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

Figure 2-8 Spalling on a Concrete Surface.
(Source: Caltrans, 2003)

### 2.4.4 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 2-9 shows efflorescence of the concrete surface.

Figure 2-9 Formation of Efflorescence on a Concrete Surface.

(Source: House Check, 2007)

### 2.4.5 Honeycombs

Honeycombs (Figure 2-10) are coarse aggregates on the surface without any mortar covering or surrounding the aggregate particles. The honeycombing may extend deep inside the concrete and are caused by a poorly graded concrete mix or by insufficient vibration at the time of placement. Honeycombing must be taken care of when noticed and repaired to prevent further deterioration of the concrete surface.

Figure 2-10 Honeycombing on a concrete surface.
(Source**:** Department of Architectural Engineering, 2006)

### 2.4.6 Popouts

Popouts are conical fragments that break out of the surface of the concrete leaving small holes as shown in Figure 2-11. Popouts occur because the concrete has been overworked, allowing the aggregates to drift upward toward the surface.

Figure 2-11 Pop-outs in a Concrete Structure.
(Source: Concrete Sealers, Specialty Coatings and Consulting, 2006)

## 2.5 Hydraulic Factors

When hydraulic factors reduce the performance of culverts, potential safety, economic, and environmental impacts may result. The flooding of adjacent properties or downstream areas from unexpected headwater depth may occur. An inadequate hydraulic performance of a culvert may damage the embankment or culvert because of erosion (FHWA, 1986). Hydraulic factors that deteriorate culverts include but are not limited to the follow.

### 2.5.1 Insufficient Capacity and Flooding

Flooding can cause overtopping of the roadway and, in extreme cases, failure of the culvert and the roadway above. In addition, flooding can damage property adjacent to the structure as well as property both upstream and downstream of the culvert. Flooding will cause incurrence of costs to the agency, the motorist, and to the owners of adjacent property (FHWA, 1986). Flooding of major urban or rural areas can be caused by culvert insufficient capacity. Insufficient capacity may be due to bad designs, blockage debris and the like. In a recent case (June $19^{th}$, 2008) covered by the Daily Courier (Connellsville, PA), a backed-up culvert ditch overflowed during two sudden, heavy rainfalls. The culvert that goes under a road, under a railroad tracks and into the river, was blocked by an illegally dumped tire. The residents of the area believe that the flooding was not caused by an act of nature, instead they think the tire helped to collect debris and subsequently reduced the hydraulic capacity of the culvert (see reference 35).

## 2.6 Operational Factors

Operational defects failure mechanism originates from an increase in demand and a decrease in capacity. Infiltration and inflow are the two types of demand on a pipe system. Infiltration increases the demand as the number of structural defects grows. Inflow is the demand on the system from service connections or storm waters or both (ASCE, 1994; EPA, 1991). A decrease in capacity is the result of a decrease in the effective diameter of the pipeline and an increase in the roughness coefficient. The effective diameter is reduced by structural defects such as open and offset joints, broken pipe sections, root masses, grease, or collected debris.

### 2.6.1 Blockages Debris

Debris carried by stormwaters can be a destructive element in culverts. However, this destructive potential is primarily related to clogging of the culvert with the attendant effects of overtopping and erosion or a single impact from a large piece of debris that causes immediate damage to the culvert. Large volumes of debris can, however, add to the effects of bedload abrasion. The potential for debris to add to abrasion will depend primarily upon the relative hardness of the debris and the culvert material. The most common types of debris that lead to major damage are boulders, trees and shrubs, and ice although, during major storm events, anything movable by stormwaters can be transported to culvert locations. Types of areas that have proven troublesome are drainages with unstable hillsides, heavily forested areas subject to fire, streams that support beaver activities, and cold weather sites where ice accumulation can block or otherwise damage drainage structures. Whenever debris is likely to pose a problem, appropriate debris control structures should be considered for installation. The most common types of debris found in culverts are boulders, trees, shrubs, ice, etc. Figure 2-12 shows the debris accumulated in a culvert.


Figure 2-12 Debris at the Opening of the Culvert

There are some countermeasures that mitigate the effects of debris on culverts. These measures were published by the Federal Highway Association (FHWA) (see reference 29). Structural measures to mitigate debris blockage in culverts are:

- Debris Deflectors
- Debris Racks
- Debris Risers
- Debris Cribs
- Debris Fins
- Debris Dams and Basins
- Or a combination of two or more devices

There are occasions where is almost impossible to mitigate the blockages by debris. Where beavers are present in the area, no matter what structural measures used they tend to build a dam at either one of the openings of a culvert or inside the culvert. Their natural instinct reduces the hydraulic capacity of culverts or its performance. One advisable recommendation might be to carry out inspections and cleaning of the culvert in a pre-determined span of time. Figure 2-13 illustrates a debris blockage by a beaver dam.

Figure 2-13 Beaver dam inside a culvert. (Patenaude, R,. 2003).

## 2.7 Other Factors

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

### 2.7.1 Culvert Size

A number of authors have investigated the relationship between pipe size and structural stability. Studies indicate that there is a decreasing trend in culvert failure rate with increasing diameter and is directly attributed to the increasing wall thickness and joint reliability with increase in culvert diameter. Larger wall thickness gives the culvert better structural integrity and improved resistance to corrosion failures.

Although longitudinal bending stresses increase with increasing culvert diameter, they do so at a slower rate than the increase in culvert's section modulus, hence culverts, which have high length-to-diameter ratios, are more likely to suffer from excessive bending stresses. Despite the fact that the above issue is well documented within the literature, there is little evidence of any numerical or statistical investigation of the effect of high culvert length-to-diameter ratios in regard to the mod of failure.

### 2.7.2 Culvert Gradient

The slope of a culvert is found to have an impact on the condition of the pipe. For all conditions the same, the steeper the slope the higher is the possibility that culvert segments deteriorate. This may be owing to the fact that steeper culvert segments include faster flow rates, resulting in greater possibility for erosion and surface wear to the inside walls or joints of culvert segments. Generation of deteriorating gases or movement of debris may also increase deterioration rates.

### 2.7.3 Culvert Depth

In investigating the effect of depth on culvert structural condition, found a steady decreasing defect rate to a depth of 18 ft, below which the defect rate began increasing with depth. It was suggested that the first occurrence probably reflected the decreasing influence of surface factors such as road traffic and utility or surface maintenance activity. The second occurrence or pattern was explained by the increasing effect of overburden pressure. Jones (1984) has suggested that, in shallow culverts, the effect of seasonal moisture variations in the soil surrounding might be significant. In an analysis of over 4400 pipe failures, Anderson and Cullen (1982) reported that 65 percent of all incidents occurred at a depth of 6.5 ft or less and 25 percent from 6.5 to 13 ft deep, although no indication is given of overall pipe depth distribution. Changes in cover depth may also be important in determining a culvert's structural stability (Najafi 2005).

### 2.7.4 Frost Heave

Frost heave is defined as the vertical expansion of soils caused by soil freezing and ice lens formation. All underground structures require the consideration of frost heave effects, as they are capable of displacing portions of the entire underground structure.

Differential heave causes sections of culvert to experience nonuniform displacements, and this result in forceful flexural stresses. Uniform heaving may also prove to be a problem under certain circumstances where culvert joints are not subject to movement. Under this scenario, the culvert experiences stresses similar to a simple beam loading, in which case the pipe will experience bending stresses. Failure of culvert joints may be the result of the frost heave process. This may be a function of the type of connection and the type of fill material used between joints.

The conditions for frost heave require the presence of a frost-susceptible soil, the presence of a sufficient water source, and a ground temperature below the freezing point.

With all of the above factors present, there is the potential for damage owing to frost heave. The propensity for heave of a soil under freezing conditions is affected by properties such as grain size, rate of freezing, the availability of water, and by applied loads.

### 2.7.5 Frost Load

The failure of culverts during winter could be attributed to increased earth loads, that is, frost loads. In a trench, the frost load develops primarily as a consequence of different frost susceptibilities of the backfill and the sidewalls of the trench and the interaction at the trench backfill-sidewall interface. Trench width, differences in frost susceptibilities of backfill and trench sidewall materials, stiffness of the medium below the freezing front, and shear stiffness and backfill-sidewall interface play important roles in the generation of frost loads. Thus, it is preferable to use a backfill material that has matching or lower frost susceptibility than that of the sidewall in order to minimize the development of excessive differential frost loads.

### 2.7.6 Soil-culvert Interaction

Soil-culvert interactions are also a possible cause of culvert deterioration. The resistance of the soil-to-culvert union is important because the shear strength of the interaction can affect the degree of mobility of the pipeline and hence its ability to displace. In cold temperatures, the bond between the soil and pipe produces the amount of restraint in the pipe to shrink axially. A high soil-culvert interaction will not allow the pipe to contract, and consequently the axial stress in the culvert will increase. It is also possible that a strong bond between an iron culvert and soil will cause excessive soil-culvert interface shear that may cause abrasion of the culvert coating. This abrasion may lead to premature corrosion of the culvert exterior.

### 2.7.7 Culvert Wall Temperature Gradients

For longitudinal failures, a failure mechanism might be when a high temperature gradient occurs across the culvert wall. If the temperature gradient can lead to unusually high hoop stresses, subsequently leading to failure.

### 2.7.8 Differential culvert temperature

Some literature speculates that a high differential temperature between the internal and external culvert wall can produce high temperature gradients. Under such conditions the inner and outer fibers will be subject to different temperature drops, resulting in differential strains and circumferential stresses.

### 2.7.9 Soil Type

The significance of the type of soil cannot be overlooked, as it is one of the most important factors, having effects on almost all of the above mechanisms. Its effects on frost heave, strength of soil-pipeline interaction, and external corrosion can be important for many failure mechanisms.

The type of soil the pipe is located in is also important for the aspect of differential heaving and thaw settlement. If a culvert is located at the interface of two different soil types, it has been shown that each soil will experience an uneven amount of frost heaving, and therefore have an influence on the amount of strain experienced by the culvert. In the same manner, thaw settlement will lead to differential stress distributions on the culvert.

Soil corrosivity is a soil characteristic that must be considered for external corrosion predictions. Physical characteristics (particle size, friability, uniformity, organic content, color, and so on) have reflected corrosivity, based on observations and testing. Soil uniformity is important because of the possible development of localized corrosion cells. Corrosion cells may be caused by a difference in potential between unlike soil types, with both soils being in contact with the pip. If it can be assumed that for a particular soil classification the approximate uniformity coefficient can be estimated, then the possibility of corrosion can be estimated.

### 2.7.10 Groundwater Level

Use of the soil water content parameter is important from several aspects. As mentioned earlier, the rate of frost heave is controlled by the availability of free water. It is also important for external corrosion.

From the perspective of external corrosion, soil corrosion aggressiveness has been related to moisture content. Soils with moisture content above 20 percent are thought to be particularly corrosive (Jarvis and Hedges, 1994). Studies substantiate that moisture content is a factor contributing to soil aggressiveness.

### 2.7.11 Overburden Pressure

Overburden pressure is thought to be important because of its ability to help characterize frost heaving and soil-pipeline resistance. It can be characterized by the depth of cover and soil density. Literature indicates that the overburden pressure is important for the rate of heaving.

From the perspective of soil-pipeline interaction, it has been demonstrated that the frictional soil resistance is affected by pipe diameter and depth (Rajani et al., 1995). Also, from the perspective of mode of failure, larger culverts are more susceptible than smaller culverts to crushing of failure. This is owing to depth, or the external loadings (i.e., roadways, large structures, and the like) to which the culvert is subjected (O'Day, 1982).

### 2.7.12 Temperature

The effects of temperature on culvert breakage rates have been observed and reported by many, Newport (1981) analyzed circumferential culvert breakage data and found that increased breakage rates coincided with cumulative degree-frost (usually referred to as freezing index in North America and expressed as degree-days) in the winter as well as with very dry weather in the summer. He attributed the increase in winter breakage rates to the increase in earth loads because of frost penetration, that is, frost loads, and the summer breakage rates to the increase in shear stress exerted on the culvert by soil shrinkage in a dry summer. He also observed that when two consecutive cold periods occurred, the breakage rates (in terms of breaks per degree-frost) in the first one exceeded those of the second one. He rationalized that the early frost purged the system of its weakest culverts, causing the later frost to encounter a more robust system.

### 2.7.13 Precipitation (Snow or Rain)

Snow cover is indicative of the insulating effect on ground temperature, as the snow will allow for the entrapment of heat into the ground. The amount of rainfall coupled with the soil type may be indicative of moisture content or hydraulic conductivity if these parameters are not measured regularly. Some literature indicates that corrosion resistance is enhanced during dry periods of the year (Smith, 1968). Therefore, inclusion of this parameter may be necessary to help characterize climatic changes as well as to infer adjustments to soil parameters.

### 2.7.14 Hydrogen Ion Concentration (pH)

In order to characterize external corrosion, it is necessary to find parameters which indicate the corrosivity of the soil. Soil pH is a good indicator of external corrosion because certain pH ranges allow for different corrosion mechanisms to occur. It has also been found that resistivity is a function of pH. For that reason, only one of the two may be required for characterization.

pH is a measure of the acidity or alkalinity of a solution. Generally soil or water pH levels between 5.5 and 8.5 are not harmful. The water is acidic if the pH is less than 5.5 and alkaline when pH is greater than 8.5 Oxygen at the metal surface is necessary for the corrosion to occur. The lowest pH levels (most acidic) are typically seen in areas that have received high rainfall over many centuries. The runoff and percolation will leach the soluble salts, with the resultant soil becoming acidic. Milder acids can be found in runoff from marshy areas, which contain humeric acid, and mountain runoff that often contains carbonic acid. Conversely, arid areas are much more likely to be alkaline due to soluble salts contained in groundwater.

### 2.7.15 Soil Resistivity

Resistivity of soil is a measure of the soils ability to conduct electrical current. It is affected primarily by the nature and concentration of dissolved salts, and the 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. The unit of measurement for resistivity is ohm-centimeters or, more precisely, the electrical resistance between opposite faces of a one-centimeter cube. Resistivity values in excess of about 5000 ohm-cm are considered to present limited corrosion potential. Resistivities below the range of 1000 to 3000 ohm-cm will usually require some level of pipe protection, depending upon the corresponding pH level (e.g., if pH $< 5.0$, enhanced pipe protection may be needed for resistivities below 3000 ohm-cm; if pH $> 6.5$, enhanced pipe protection may not be needed unless resistivities are below 1500). As a comparative measure, resistivity of seawater is in the range of 25 ohm-cm, clay soils range from approximately 750 to 2000 ohm-cm, and loams from 3000 to 10 000 ohm-cm. Soils that are of a more granular nature exhibit even higher resistivities. Some entities use the reciprocal of resistivity, conductivity, as the criterion for corrosive potential.

Corrosion can be induced by electric current in proximity to the pipe. Most often affecting metal pipe, reinforcing steel in concrete pipe may also suffer an increased rate of corrosion. Typical sources of stray current are electrified rail lines, high tension electric transmission lines, and cathodically protected structures (gas transmission mains). Protective coatings are usually applied to the pipe to negate the effects of stray electric currents.

### 2.7.16 Chlorides

Dissolved salts containing chloride ions can be present in the soil or water surrounding a culvert. Chlorides will also be of concern at coastal locations or near brackish water sources.

Dissolved salts can enhance culvert durability if their presence decreases oxygen solubility but, in most instances, corrosive potential is increased as the negative chloride ion decreases the resistivity of the soil and/or water and destroys the protective film on anodic areas. Chlorides, as with most of the more common corrosive elements, primarily attack unprotected metal culverts and the reinforcing steel in concrete culverts if concrete cover is inadequate, cracked, or highly permeable.

### 2.7.17 Sulfates

Sulfates can be naturally occurring or may be a result of man's activities, most notably mine wastes. Sulfates, in the form of hydrogen sulfide, can also be created from biological activity, which is more common in wastewater or sanitary sewers, and can combine with oxygen and water to form sulfuric acid. Although high concentrations can lower pH and be of concern to metal culverts, sulfates are typically more damaging to concrete. Typically, the sulfate in one or more various forms combines with the lime in cement to form calcium sulfate, which is structurally weak. Concrete pipe is normally sufficient to withstand sulfate concentrations of 1000 parts per million (ppm) or less. For higher concentrations of sulfates, higher strength concrete, concrete with lower amounts of calcium aluminates (under 5 percent) or special coatings may be necessary.

### 2.7.18 Industrial Effluents

Industrial effluents can contain compounds that are extremely destructive to pipe materials. Waste streams from most industries are sufficiently regulated to be of limited concern to the highway engineer. However, tailings from mining operations can be a source of highly acidic runoff, as can livestock operations or illegal connections from residential or small commercial lots. Potentially corrosive runoff can also be of concern at locations known for a high probability of accidental spills (e.g., runaway truck escape ramps). An assessment of the constituents and their possible concentrations in the streamflow should be performed whenever industrial effluents are suspected. If the source can be identified, corrective action can usually be taken.

## 2.8 Modes of Culvert Deterioration

As explained at the beginning of the chapter, culvert deterioration is a complex process; that is affected by many factors such as deterioration, failure-structural, hydraulic, environmental, functional, age of the pipe, quality of initial construction, and so on. The intensity of structural failures depends on the size of the defect, soil type, interior hydraulic regime, groundwater level and fluctuation, corrosion, method of construction, and loading on the pipe. Figure 2-14 illustrates various kinds of internal and external forces acting on a pipe. The modes of failure depend on the type of environment and pipeline material.

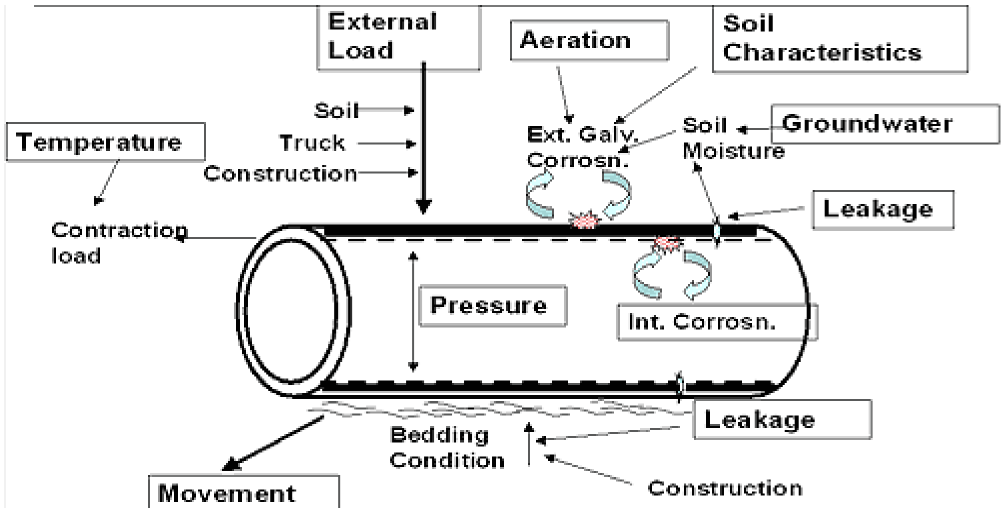


Figure 2-14 Pipeline and culvert interactions leading to failure (O'Day et al., 1986)

Culvert breakage is likely to occur on pipes whose structural integrity has been compromised by corrosion, degradation, inadequate installation, or manufacturing defects.

## 2.9 Age of Culvert

A classical survival function relating the age of the pipeline to the failure rate is denoted by a bathtub curve as shown in Figure 2-15. The early part of the curve shows infantile failure which for pipes is representative of failure due to human factors in the actual laying of the pipe (manufacturing faults, tend to appear during that part). For instance, it is commonly assumed that the older the pipes, the poorer the pipe condition; however, this is often not the case and collapse events sometimes happen with young pipes, resulting in a reduced level of serviceability (Trans et al, 2006). A period of the time follows in which failure rate is generally low. When failure does occur it may depend on many factors, such as excessive loads not designed for, or settlement. As the pipes tend toward the end of their useful life the failure rate increases exponentially. This classic survival profile is known as the bathtub curve. The bathtub curve can be applied to an individual pipe, a group of pipes with similar characteristics, or the whole population of a pipe network

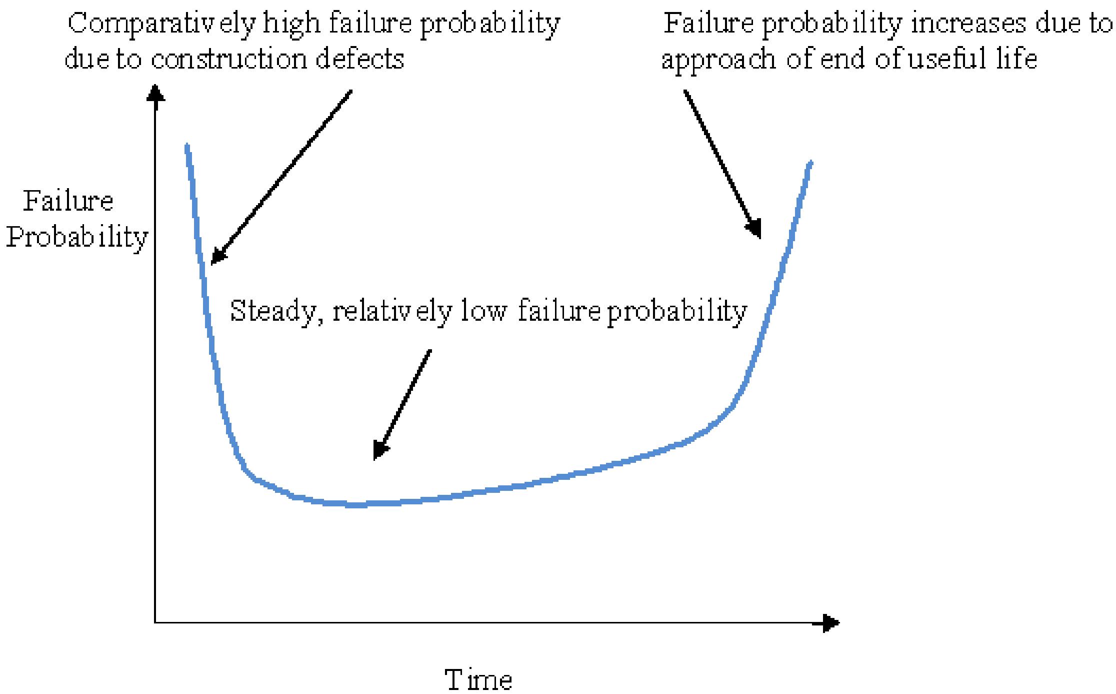


Figure 2-15 Bathtub curve of a pipe and culvert performance with age.

# CHAPTER 3
# USE OF TRENCHLESS TECHNOLOGIES FOR CULVERT RENEWAL

## 3.1 Culvert Inspection

> "Over the years, culverts have traditionally received less attention than bridges. Since culverts are less visible it is easy to put them out of mind, particularly when they are performing adequately. Safety is the most important reason why culverts should be inspected."
>
> (CALTRANS, 2003)

The trenchless culvert renewal starts with inspection of the existing culvert. The trenchless method must be applicable to the conditions of the culvert and the nature of the problems involved. Therefore, periodic culvert inspection is very important to help define and prevent future problems. A study performed by ASCE concluded that the most important maintenance activities are inspections and cleaning.

Inspection of culverts must be planned based on several factors such as:

Problems: Their frequency and location; 80 percent of problems occur in 25 percent of the system.

Age: Older systems have a greater risk of deterioration than newer ones.

Culvert material: Culverts constructed of materials that are susceptible to corrosion have a greater potential of deterioration and collapse. Nonreinforced concrete culverts can also be susceptible to corrosion.

Capacity: Culverts that carry larger volumes take precedence over culverts that carry a smaller volume.

Location: Culverts located on shallow slopes or in flood prone areas have higher priority.

Subsurface conditions: Depth to groundwater, depth to bedrock, soil properties (classification, strength, porosity, compressibility, frost susceptibility, erodibility, and pH).

Corrosion: Hydrogen sulfide ($H_2S$) is responsible for corroding culverts, structures, and equipment used in drainage systems. The interior conditions of the culvert need to be monitored and treatment needs to be implemented to prevent the growth of slime bacteria and the production of $H_2S$ gases.

There are several key activities that must always be performed during a culvert inspection to ensure that a culvert is functioning adequately. The inspection should evaluate structural integrity, hydraulic performance and roadside compatibility (CALTRANS, 2003). These activities can be classified into three different groups. The first group, including conventional Closed-circuit television (CCTV) examinations, are techniques that determine the condition of the inside surface of the culvert. The second group examines the overall condition of the culvert and wall, in some cases, the soil around the culvert. Finally, the third group detects specific problems within or outside of the culvert wall.

The California Department of Transportation (CALTRANS, 2003) prepared a list of key elements to inspect in a culvert, these elements can provide an extra critical factors when a trenchless renewal method is necessary, the elements are listed as follows:

a) Review available information: Roadway and culvert Design, ADT/Truck Traffic, Maintenance History, Design Q – Headwater/Velocity, pH of water and soil, Resistivity of soil, Water Table.

b) Observe overall condition.

c) Inspect approach roadway, pavement and embankment based on their interaction with the culvert and end treatments.

d) Inspect upstream and downstream waterways based on their interaction with the culvert and end treatment. The inspection should include an assessment of the vegetation, slope, and type of water system, scour, high water marks, changes in drainage area and land-use.

e) Assess the condition of the end treatment and appurtenant structures including their ability to pass flows.

f) Assess the condition of the culvert barrel by inspecting joints, the degree of deterioration of the culvert material, deformation, alignment, and the culverts ability to pass its design flow. To achieve this, it could be necessary to use a CCTV equipment.

## 3.2 Trenchless Culvert Renewal

The problems related to open cut replacement can be eliminated by using trenchless techniques. Trenchless methods provide safer working environment for workers and avoid the disruption of the traffic. The disadvantage of trenchless methods might be their high initial cost and they may not be suitable for every site due to the space requirements and/or surrounding terrain.

In this report, renewal methods of culverts are going to be defined as renewal methods in which the partially or fully deteriorated pipe is used as the host pipe and a new pipe is formed within this host pipe. In order to address this topic (9) nine trenchless techniques will be explained in detail

- Sliplining

- Cured in place pipe (CIPP)
- Spiral wound pipe
- Close-fit pipe
- Thermoformed pipe
- Panel lining
- Coatings and linings
- Formed in place pipe
- In line replacement

For each one of the trenchless techniques the following characteristics are explained in detail:

- Introduction and background
- Product main characteristics
- Advantages and limitations
- Method Installation description
- QA/QC

### 3.2.1 Continuous Sliplining and Segmental Sliplining

#### 3.2.1.1 Introduction and Background

This technique is one of the earliest and simplest forms of trenchless culvert renewal methods and can be used for structural or nonstructural renewal processes. Sliplining has been used for more than 60 years, showing that is a proven cost-effective renewal technique, with minimum disruption of service, surface traffic and minimum property damage. Figure 3-1 shows a renewed culvert by the use of sliplining method.

Figure 3-1 A culvert renewed by sliplining.
(Source: Terrafix Geosynthetics Inc.)

Sliplining is the process of inserting a new pipeline into an existing culvert and grouting the annular space. The new pipeline should be selected as a different material, which is more resistant to environmental factors in order to eliminate the previously faced problems. Although sliplining decreases the total cross sectional area of a culvert, using a smoother pipe material with a smaller Manning's Roughness coefficient may eliminate this problem. In order to have a successful sliplining, the existing culvert must be inspected for any bends or irregularities, which may obstruct the pulling or pushing of the new pipe. Once the inspections are completed, the host pipe should be cleaned and prepared for sliplining. The new pipe segments should be joined together, inserted into the existing pipe and positioned. Final step is to grout the annular space between the new lining pipe and the old culvert. Grouting must be completed in phases in order to prevent the new lining material from floating and to have good bonding between the new lining material and the old culvert.

### 3.2.1.2 Product Main Characteristics

Sliplining can be used to install a new pipe of up to 10 percent smaller diameter compared to the culvert. The greater of either the outside diameter of the slipline pipe or coupler (if applicable) should be compared to the inside diameter of the culvert. This may be accomplished by attempting to pull a short section (~5 feet in length) through the culvert as a trial run. The culvert should be clean; free from sediment and debris so as to not interfere with the installation of the liner pipe. Sliplining installations may be subject to thermal length changes and should be designed with a minimum clearance between the slipline pipe's outside diameter and the culvert's inside diameter.

Typical insertion distance limits are product specific and can range from 200 ft to up to 2000 ft. Some items that need to be considered when evaluating sliplining lengths are frictional forces that will be anticipated and the strength of the product that will be required to offset these forces. The frictional forces that are anticipated will be dependent on the condition of the culvert. Since these factors will be project specific, additional contact with the product manufacturer is recommended. Continuous sliplining joints are typically butt-fused; on the contrary, segmental sliplining typically uses push-together joints providing a leak free seal. The recommended maximum grouting pressure for water tight pipe products is 5 psi. A maximum of one degree joint misalignment can be accommodated.

Table 3-1 Main characteristics of CIPP

| *Method* | *Diameter range (in)* | *Maximum installation (ft)* | *Grouting* | **Liner material** |
|---|---|---|---|---|
| Segmental | 24-160 | 200 – 2000 | Requires a thin, coarse mortar. | Polyethylene, Polypropylene, PVC, Glass Reinforced Pipe |
| **Continuous** | 12 - 63 | 200 - 2000 | Requires a thin, coarse mortar. | Polyethylene, Polypropylene, PVC |

Original design calculations may be referenced; however careful attention should be given to changes in land use which would change the calculated runoff tributary to the culvert. Once a discharge has been determined, the required size of the slipline pipe may be established. If original design calculations are not available, the project engineer should complete a thorough drainage study. A culvert size can be selected based on watershed attributes, design storm, allowable headwater, culvert entrance conditions and any other related design factors.

In many cases, where culverts are too deep to make replacement practical, slightly reduced hydraulics may be an acceptable tradeoff to an expensive replacement. Typically, gravity flow systems are designed using Manning's Equation with a conservative 'n' value of 0.012 for pipe. It should be noted that culverts in need of relining do not have Manning's 'n' values typical of original design values. Relining with smooth interior pipe may actually increase the capacity of the deteriorated culvert or storm sewer.

#### 3.2.1.3 Advantages and Limitations

Advantages of sliplining include:

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

Some of the limitations of sliplining are:

- Host diameter is typically reduced by ~10%, however, due to the liner pipes' good flow characteristics; the hydraulic capacity is frequently improved.
- Grouting is required.
- Segmental installations, cannot typically push through angle points greater than 1 to 3 degrees (depends on diameter and clearance).

#### 3.2.1.4 Method Installation Description

Before the slipline pipe is inserted into an existing culvert for relining, it is critical to inspect the existing culvert for any objects or obstructions, which may be extending into the barrel of the existing culvert to be relined. Any existing obstructions in the host pipe need to be removed prior to sliplining. Failure to do this may result in a damaged reline. Existing flow should be eliminated or kept to a minimum. Excessive flow can not only interfere with the sliplining and grouting procedure but can also create severe safety issues during the installation process (ASCE, 2008).

Once the culvert is clear, the new material may be pushed through the open end. It is important to determine the maximum insertion force that can be applied to the culvert. This will prevent the pipe wall profile from buckling in the axial direction under excessive insertion loading.

In cases where the new culvert will be two or more sizes smaller than the existing culvert, it is possible to construct mechanisms to transport the new material along the existing culvert without sliding across the invert. Although ideal for construction, many times there is insufficient room to allow this technique.

When relining a culvert with slipline pipe, it is recommended to fill the void space between the existing culvert and the new material with a grout material. The grout material is often a controlled low strength material – controlled density fills (CLSM-CDF). A CLSM or flowable fill material will help provide uniform support on the sides of the pipe, maintain a consistent soil density, provide lateral support for the pipe, eliminate point loads and minimize effects of hydrostatic pressure if applicable. In cases where the existing invert has deteriorated or is completely destroyed, the grout material will fill any fractures or holes in the existing culvert (ASCE, 2008). In the case where the grouting must be pumped into the annular space, special care is advice to not exceed the pressure required by the manufacturer. Culverts and storm drainages renewed by sliplining could collapse if excessive grouting pressures are used (ISCO Industries 2005).

To ensure proper alignment and prevent joint separation, the pipe should be anchored against flotation when placing the grout material. Grouting in lifts is recommended to help minimize effects from floatation. Each lift should be allowed to set up between pours. Contractors may have other techniques that will also prevent flotation such as the use of deadweight inside the pipe. Regardless of the method used, it is also important to avoid applying point loads to the pipe.

It is important not to use excessive grout pressure. In most circumstances, the joint, not the wall strength, will be the limiting factor for maximum allowable grouting pressure. During the grouting operation, gauges should be used to monitor the grout pressure exerted on the pipe system. For some applications, hydrostatic head pressure may increase the expected pressure on the pipe from the grouting. Additional pressure may be a result of the slope and/or diameter of the pipe, elevation changes between the pipe and the gauge, and other conditions that should be considered during the design. The sum of all pressures that will be exerted on the pipe should not exceed the recommended maximum pressure for the application.

Pipe misalignment at the joint can be incorporated to address a bend or angle in the host pipe. Please refer to the product specific information for additional information on limitations of this misalignment. The annulus at the open end(s) should be bulkheaded to prevent the grout material from exiting the installation at that area.

In a nutshell the installation procedure for sliplining must follow the next steps:

- Assess host line condition & configuration (diameter, grade, sags, collapses, angles, debris, etc.)
- Determine liner pipe diameter for proper fit insertion & hydraulic needs.
- Remove any debris and repair collapses in the host, so the liner pipe may be inserted. No bonding is required, so surface cleaning is not needed.
- Verify sufficient clearance for the liner pipe insertion (measurements or by pulling a mandrel).
- For continuous sliplining: slide butt-fused pipe into the culvert by pulling from the open end.
- For segmental sliplining: slide liner pipes into the culvert by pushing from the open end.
- Bulkhead annulus at the open ends
- Fill annulus with grout (may require blocking or ballast to fix the liner pipe position).

#### 3.2.1.5 QA/QC

- Verify liner pipe is undamaged from insertion and grouting by inspection via walk through or video.
- Verify all joints are fully assembled by inspection via walk through or video.
- Verify liner pipe deflection is </= 5% (if some distortion is noticeable).
- If required, leakage test the installed by infiltration, exfiltration or air testing.

### 3.2.2 Cured In Place Pipe (CIPP)

#### 3.2.2.1 Introduction and Background

Cured-in-place-pipe (CIPP) was the first truly trenchless full pipeline renewal process. Invented in 1970, the first commercial project was completed in the United Kingdom in 1971, and it was introduced into the United States in 1976. In the late 1970s to early 1980s a number of private construction companies were licensed to install this unique technology. With regional education, marketing and occasional installations underway, the CIPP technology became more popular. Owners however, needed a number of additional years to develop confidence for its large-scale use (NASSCO, 2007). As of 2008, it is estimated that over 25,000 miles of CIPP have been installed worldwide.

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

### 3.2.2.2 Product Main Characteristics

There are many different kinds of CIPP products and processes. However, CIPP generally involves manufacturing a fabric tube of the length and diameter of the host pipeline. The wall thickness of the fabric tube is designed depending upon the installation process, end service and physical properties of the finished CIPP laminate. The fabric tube is saturated with a liquid thermosetting resin, inserted into the host pipeline and inflated with air or water pressure. The resin is then cured by one of several different methods (hot water, hot air, steam, UV light or at ambient temperature), resulting in a new tight-fitting plastic pipe within the host pipe. Once the ends are trimmed and any side connections opened, the renewed host pipeline is returned to service.

Although CIPP is used for storm sewers, water lines, and industrial and other process piping, historically it has principally been used for sanitary sewer renewal. CIPP is routinely used for manhole-to-manhole installations in sanitary sewers. While excavation is typically not required for small to medium sized sanitary sewers, larger sewers (48 inch equivalent diameter or larger) may require removal of a portion of the manhole or excavating a pit or shaft.

A large majority of CIPP installed as of 2008 has used the hydraulic pressure of water to install the CIPP tube and heated water to cure heat-initiated resin. During the hot water cure cycle, small amounts of organic chemicals such as styrene can leach into the cure water. This hot water cure process is quite acceptable in sanitary sewers because the waste process water can safely be discharged to the sanitary sewer system. However, this waste process water should not be discharged to the environment. Thus, if water is used to install and cure CIPP for culverts or storm sewers, the waste process water must either be pumped to an adjacent sanitary sewer system or hauled to a suitable disposal site. Depending on the project location and logistics, this process can be cost prohibitive. Many rural culverts are long distances from water sources and suitable cure water disposal sites. As a result, water must be hauled to the job site, used during the installation, and then collected and hauled away from the job site to a suitable disposal location. These additional costs can yield a project not cost-effective.

### 3.2.2.3 Advantages and Limitations

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

Advantages of CIPP include:

- Grouting is not necessary.

- Smooth interior surface enabling an increase in flow capacity.
- Lining noncircular shapes is possible.
- Lining can be accomplished even in the presence of bends.
- Design life of 50 – 100 years.
- Corrosion resistant.
- Relatively quick installation.
- A structural solution.
- Small cross-section reduction with increased flow capacity.

Limitations of CIPP include:

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

### 3.2.2.4 Method Installation Description

CIPP installation and cure methods that do not use large amounts of water are better suited for the renewal of many storm sewers and culverts. If large amounts of water are not used in the process, water does not have to be trucked to and away from the job site.

Three different types of installation processes are discussed below. Each uses pressurized air to install and/or inflate the CIPP tube and steam, hot air, UV light or simply ambient temperature to cure the resin once the CIPP tube is in place. There are a large number of CIPP products, processes and installers available in the North American market, and each is slightly different with varying technical envelopes. However, considering that the scope of this manual includes open-ended storm sewers and culverts with an equivalent diameter range of 12 – 144 inches, CIPP products and processes are available for storm sewers and culverts in the equivalent diameter range of 12 –108 inches. Of course CIPP is available for sewers smaller than 12-inch diameter, but that is outside the scope of this report (ASCE, 2008).

Table 3-2 Main characteristics of CIPP

<table>
<tr><th>Method</th><th>Diameter range (in)</th><th>Maximum installation (ft)</th><th>Resin</th><th>Liner material</th></tr>
<tr><td>Inverted with air</td><td>12 -108</td><td>3000</td><td>Polyester and vinyl ester resins</td><td rowspan="2">Polyester felt material, fiberglass reinforced or similar</td></tr>
<tr><td>Winched at place</td><td>12 - 100</td><td>1500</td><td>Polyester and vinyl ester resins</td></tr>
</table>

### 3.2.2.4.1 Invert with Air

Wall thickness design and installation of CIPP utilizing the inversion process is described in ASTM F 1216 (ASTM. 2007). Once the host pipeline has been cleaned and prepped, the CIPP tube is saturated with liquid thermosetting resin, a polyester resin for storm sewers and culverts. This commonly called wet out process typically occurs in a factory setting but can also take place at the job site if the wet out tube is too large or heavy to transport. Once the wet out tube is on the job site, the installation process can begin.

Although there are many different combinations of CIPP tube types and installation equipment available, in nearly all cases the beginning of the CIPP tube is turned inside out and attached to some type of inversion device. Air pressure is added to a sealed chamber causing more of the CIPP tube to turn inside out or invert. As the inversion process continues the inverting face of the CIPP moves through the host pipeline. When the tube is half inverted or half way into the host pipeline, the last of the wet out tube moves into the inversion device. Depending upon the type of installation being utilized, at this time a rope may be attached to the end of the CIPP tube. In addition, hoses may also be attached to deliver air and steam throughout the CIPP tube once it is fully inverted (ASCE, 2008).

As the inversion continues, tension is maintained on the previously attached rope (often called a hold-back rope) to control inversion rate, and the inverting face continues to move to the termination point. This rope and any previously attached hoses have now traveled through the entire length of the host pipeline.

With the inversion process, resin saturated felt is pressed up against the host pipe. Because of this, care must be taken to prevent liquid resin from flowing into the receiving stream or downstream storm sewer.

Most air-inverted CIPP tubes are cured with steam. In this case steam is either discharged into the attached hoses or directly into the CIPP tube. Once a previously determined cure schedule has been satisfied, the now cured product is cooled with air. Once cool, the ends are trimmed, any side connections are reinstated and the storm sewer or culvert can be placed back into service.

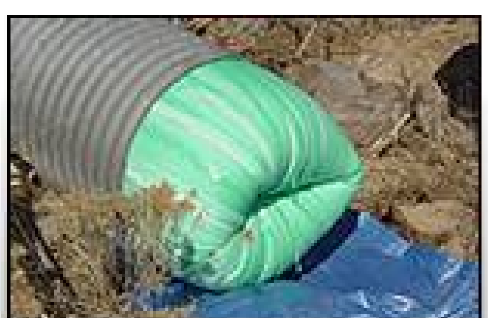

Figure 3-2 CIPP Inversion with air pressure.
(Source: Hydro Tech Inc.)

### 3.2.2.4.2 Pull-in and Inflate

Wall thickness design and installation of CIPP utilizing the pull-in and inflate process is described in ASTM F 1743 (see reference 7). Once the host pipe has been cleaned and prepped, the polyester resin saturated CIPP tube is pulled into the host pipe. Once the pull-in process is completed, the CIPP tube is inflated with air. In order for this process to work, the CIPP tube must have a coating or bladder on the inside that allows the tube to be inflated. The CIPP tube must also have a coating on the outside to allow the tube to be impregnated with resin, and also to protect the saturated tube during the pull-in process. Because the resin is contained between an outer and inner membrane or coating during the installation process, the chance that any liquid resin will escape into the environment is minimized (ASCE, 2008)..

Once the CIPP tube is pulled-in and inflated with air, it can be cured with UV light, steam or hot air. Once cooled, the ends are trimmed, any side connections are reinstated and the storm sewer or culvert can be placed back into service.

Figure 3-3 Pull and Inflate process (NASSCO, 2007).

### 3.2.2.4.3 Pull-In and Invert Through

Wall thickness design and installation of CIPP utilizing the pull-in and invert-through process is described in ASTM F 1743 (see reference 7). Two CIPP tubes are required for this process. Once the host pipeline has been cleaned and prepped, the CIPP tubes are saturated with liquid thermosetting polyester resin or wet out. Typically the bulk of the finished wall thickness, and, thus, resin is placed in the tube that is pulled-in (Tube A). The inverted tube (Tube B) may include a thin layer of fabric to be wet out. Or, it can simply be a bladder material with no fabric, requiring no wet out (ASCE, 2008).

First, Tube A is pulled into place. Tube B is then inverted with air through Tube A. Inversion of Tube B is as described in “Invert with Air”. This process inflates Tube A and holds it in place tight against the host pipeline. Steam is then introduced to cure the resin. If Tube B included a fabric material that was wet out, Tube A and Tube B cure together forming one laminate. If Tube B is simply a bladder material with no wet out fabric, it is typically extracted and discarded. With this process the resin is contained between an outer and inner membrane or coating during the cure process thus minimizing the chance that any liquid resin will escape into the environment.

Consider using this process for an 84-inch culvert. Assuming a wall thickness design of 36 mm, a typical scenario would be a 33 mm thick Tube A and 3 mm thick Tube B. The 33 mm Tube A is first pulled into the culvert, the 3 mm Tube B is then inverted through Tube A and then the two tubes are cured together achieving the desired thickness.

This process is advantageous for difficult to access locations. Tube A can be lowered in with a crane and pulled-in with a cable and winch. Air inverting the 3 mm thick Tube B is much easier and does not require the large set-up area when compared to inverting a 36 mm tube.

Once cured and cooled, the ends are trimmed, any side connections are reinstated and the storm sewer or culvert can be placed back into service.

#### 3.2.2.5 QA/QC

The contractor installing the CIPP should take quality assurance measures during the installation process to ensure that quality controls listed in the contract documents are met. This process is more easily accomplished if the contactor has a permanent quality program in place.

The testing requirements to determine if the installed CIPP meets the performance requirements of the contract documents are typically listed in the technical specifications. Also, the basic testing requirements outlined in ASTM F 1216, ASTM F 1743 and ASTM D 5813 are applicable to storm sewers and culverts. These include:

- Workmanship: This includes a visual inspection for dry spots, lifts, delaminations or other defects. This inspection is by closed-circuit-television (CCTV) for small pipes or a walk-through on larger storms sewers or culverts.

- Flexural Properties: Flexural strength and flexural modulus are determined from a CIPP sample collected at the jobsite. These values should meet or exceed the values specified.

- Wall Thickness: The in-place wall thickness should meet or exceed the specified minimum wall thickness including any +/- tolerances.

- Chemical Resistance: Although chemical resistance properties are not as important in a storm sewer or culvert as compared to a sanitary sewer, the materials installed should meet the requirements of the chemical resistance test in ASTM F 1216.

- Tensile Strength: Tensile strength testing is not required for CIPP used to renew storm sewers, culverts or sanitary sewers. Tensile testing is required only for pressure CIPP.

Conformance to performance-based requirements is a true indication of the installed CIPP's ability to perform satisfactorily over the expected design life of the project. Strict means and methods specifications can be restrictive and exclusive because there are several types of CIPP installation methods and numerous CIPP installers in the marketplace.

Inspector's qualifications and responsibilities also determine how the final CIPP installation performs. The inspector must become thoroughly familiar with the contract documents for the project and most importantly the detailed specifications. The detailed specifications guide the inspector to the areas where the trenchless project must be inspected, recorded, documented, tested and otherwise verified to ensure that the product is being installed as specified (NASSCO, 2007).

Among some of the quality control procedures, it is recommended by the ASTM D5813 that for each inversion designated by the owner, a specified number of CIPP samples must be required. The sample should be cut from a section of the CIPP at the termination point that has been inverted through. If the CIPP is used to repair large diameter culverts, the sample should be fabricated from material taken from the tube and the resin/catalyst system used and cured in a clamped mold placed in the tube when circulating heated water is used and in the silencer when steam is used (NASSCO, 2007).

The finished CIPP should be continuous over the entire length of the culvert and e free of dry spots, lift, and de-lamination. If these conditions are present, the CIPP will be evaluated for its ability to meet the applicable requirements of the contract documents. Where the CIPP does not meet the requirements of the contract documents or specifically stated requirements of the specifications, the affected portions of CIPP will be removed and replaced with an equivalent repair (NASSCO, 2007).

## 3.2.3 Spiral Wound Pipe

### 3.2.3.1 Introduction and Background

The Spiral Wound Lining System utilizes a rigid plastic profile that is closely formed inside an existing pipe by interlocking the continuous strips of plastic profile using a specially designed winding machine or by manually locking the successive wraps of profile utilizing a jointing strip. The system is able to rehabilitate circular shape pipes as well as non circular shape pipes such as box culverts and horseshoe shapes (ASCE, 2008).

All the materials and equipment required to carry out a spiral wound project can, if required, be entered into the existing pipeline through manholes. The equipment is designed for assembly inside the pipeline with the equipment road surface footprint at a minimum.

A spiral wound lining system can be designed and installed either for corrosion protection or as a fully structural renewal for existing pipelines. Spiral Wound Lining System has the ability to rehabilitate straight pipe lengths as well as bends curves within existing pipelines. The Spiral Wound Lining System creates a rehabilitated conduit with improved chemical resistance characteristics, improved flow coefficients and where required, structural enhancement for the host pipe.

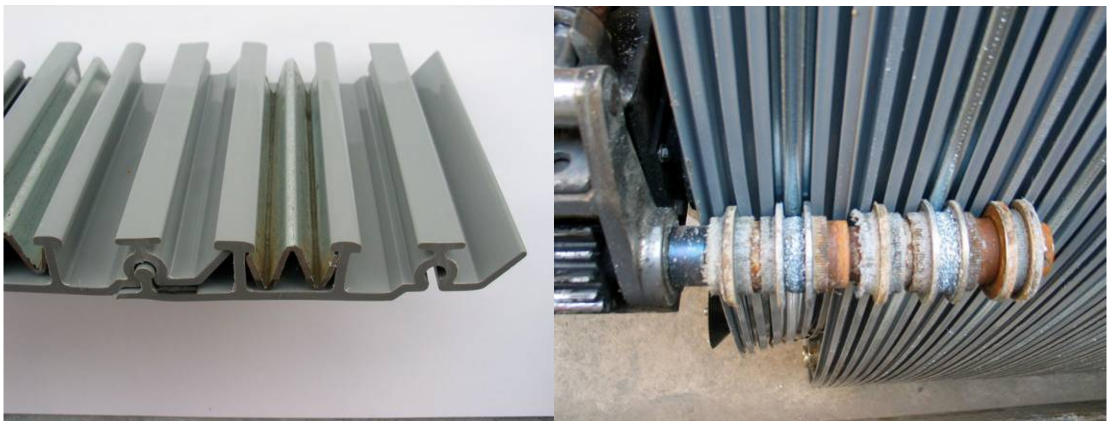

Figure 3-4 Spiral wound profile and joint (ASCE, 2008).

#### 3.2.3.2 Product Main Characteristics

Spiral Wound Lining Systems can accommodate round pipes upwards from 6 inch in diameter and non-round pipes from 42 inch and upwards. It is noted that for non-round pipes the spiral wound system does require man entry to execute the process. Table 3-3 summarizes some of the important characteristics of Spiral Wound Pipe.

Table 3-3 Main characteristics of Spiral Wound Pipe (FHWA. 2005).

| *Diameter range (in)* | *Maximum installation (ft)* | *Grouting* | **Liner material** |
|---|---|---|---|
| **12 - 120** | Unlimited | Some times required. (Cementitious Grout) | PE, PVC, PP, PVDF |

PE – Polyethylene, PVC – Poly(Vinyl Chloride), PP – Polypropylene, PVDF – Poly-Vinylidene Chloride

The Spiral Wound Lining System is able to rehabilitate round pipes, square and rectangular box section pipes as well as horseshoe shaped pipes (see Figure 3-5). The spiral winding system is not limited to straight pipe renewal as curves and bends can also be seamlessly accommodated.

Figure 3-5 Different rehabilitated culvert shapes (ASCE, 2008).

Depending on the condition of the host pipe, the design of the Spiral Wound Liner Pipe is carried out based on either a Partially Deteriorated Host Pipe Design or a Fully Deteriorated Host Pipe Design.

Partially Deteriorated Host Pipe Design

In a partially deteriorated pipe design the host pipe is assumed able to support the soil and surcharge loads through out the design life of the rehabilitated pipe with the soil adjacent to the existing pipe providing the required side support and bedding. The spiral wound pipe shall be designed to withstand ground water hydrostatic pressure without buckling.

Fully Deteriorated Host Pipe Design

In a fully deteriorated pipe design the Spiral Wound Liner Pipe is designed to support all hydraulic, soil and live loads specified in the project specifications (with safety factor). Two distinctive design theories are used in the design of Fully Structural Spiral Wound Liner Pipe.

The first design theory looks at rigid plastic pipe design theory that utilizes the rigidity/stiffness of the plastic profile combined with the supporting modulus of soil reaction to determine the maximum external pressure allowed before the Spiral Wound Liner Pipe buckles.

The second design theory looks at the composite structure of Spiral Wound Liner Pipe, Grout, and any Residual Structural Capability of Existing Host Pipe as one structural unit. The design of this particular theory is either based on Reinforced Concrete Pipe Design or based on WRc Type I Design. It is noted that without accurate empirical test data proving that composite action between the grout and the host pipe occurs, most owners are reluctant to consider the residual structural capability of the host pipe and therefore the resulting Fully Structural Spiral Wound Liner Pipe being analyzed will be over designed.

Each manufacturer of the Spiral Wound Lining System has undertaken testing to determine the durability of their product for a 50 year design life. This includes the testing of plastic's short and long term tensile and bending stresses, the flexural modulus, etc to make sure that the structural capability of the plastic is sustained over 50 years. Also, the design of the water way thickness is such that the final spiral wound liner pipe will resist a minimum of 50 year abrasion from sand and other solid item that might be flowing through the pipe.

Some unevenness in wall roughness can be found in all commercially available pipes. In spirally wound liner pipe, there is also irregularity of surface due to the spiral wound joint connecting each successive profile wrap. However, documented testing by the spiral wound pipe manufacturers has shown little difference in roughness coefficient exists between regular PVC pipe and the spiral wound pipe.

Modifications for culvert applications using a Spiral Wound Lining System are minimal. When rehabilitating corrugated metal pipe, additional bottom railing may be needed to guide the wound liner pipe into the host pipe so that it does not get caught by the corrugations within the host pipe.

Also, unlike sanitary sewer, the defects observed on storm sewer and culverts usually occur on the bottom of the host pipe instead of the top. If the bottom of the storm sewer and/or culvert is severely corroded, the bottom needs to be repaired prior to the installation of the spiral wound liner pipe.

#### 3.2.3.3 Advantages and Limitations

Advantages of spiral wound pipe include:

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

Limitations of spiral wound pipe include:

- Skillful personnel are needed.
- Annular space should be grouted.
- Dependency on a special winding machine.

- Reduction of sectional area, however an improvement in the roughness coefficient will compensate for this size reduction in most cases.

### 3.2.3.4 Method Installation Description

In this method of culvert renewal, a new lining pipe is obtained by spirally winding a polyvinyl chloride strip by using a special winding machine on the job site. The continuous spiral lining is watertight and fits very closely to the existing structure, the annular space left between the new liner, and the existing culvert should be grouted. In the case of installation by winding machine, there are two categories: a stationary winding machine or a traveling winding machine.

#### 3.2.3.4.1 Stationary winding machine

The winding machine is placed in the manhole or insertion pit and oriented so that the plastic profile can be spirally wound and inserted directly into the existing pipe. The plastic profile is fed into the winding machine that forms the profile into the required spiral wound liner pipe diameter. Simultaneously, this newly created pipe rotates and is pushed into the host pipe. Figure 3-6 illustrates the use of this machine.

Figure 3-6 Spiral wound stationary winding machine (ASCE, 2008).

#### 3.2.3.4.2 Traveling winding machine

The winding machine itself is placed into the host pipe through an existing manhole or convenient opening and is allowed to travel directly within the host pipe while forming the spiral wound new pipe. The plastic profile is fed into the winding machine that rotates and moves along the existing pipeline forming the new spiral wound round or non-round pipe shape and size. As this process leaves the wound pipe behind the machine, there is no friction between the formed profile and the host pipe. As a result, much longer installation lengths are possible.

Figure 3-7 Manual Installation (ASCE, 2008).

Manual installation requires each successive profile wrap to be manually locked together by installing a profile locking strip and manually hammering into place.


Figure 3-8 Annular space grouting (ASCE, 2008).

Depending on project specification and design, grout may be needed to fill the annular space between the new installed spiral wound liner pipe and the host pipe. The grout may be injected at openings in the end seals, at reconnected services connections, at grout holes drilled in the spiral wound liner pipe or at grout holes drilled from ground surface. Prior to commencing the grouting operation, all service openings must be opened and steps taken to prevent the grout from entering the service connections or the spiral wound liner pipe.

The grouting operation may take place in one lift or several lifts. When grouting in one lift, a bracing system will need to be installed within the spiral wound liner pipe to ensure that the newly wound liner pipe does not buckle due to the weight of the injected grout. When grouting in multiple lifts, a bracing system may or may not be required.

In the case where a bracing system is not installed, the amount of grout injected for each lift is limited by the spiral wound liner pipe deflection. The manufacturer of the spiral winding pipe system will determine grout pressures to be used. Regardless of whether a bracing system is used or not methods must be adopted to prevent flotation of the profile during the grouting process.

#### 3.2.3.5 QA/QC

The plastic profile used in the Spiral Wound Lining System shall be distinctly marked on its surface at appropriate intervals with a code number identifying the manufacturer, plant, date of manufacture and profile designation. When structural grout is required by the design, the grout should be sampled and tested as designated by the owner. The property that should be tested may include compression strength test, bleed test, shrinkage test, flowability test, etc. After the completion of installation, the Spiral Wound Liner Pipe should be inspected either by physical visual inspection or by closed circuit television.

The spiral wound pipe shall be wound continuously over the entire length of the host pipe and be free from defects such as foreign inclusions, holes, cuts, tears, and grout voids. Any splices or grout holes should be repaired by manufacturer recommended material, and no infiltration of ground water through the spiral wound liner pipe shall be observed. All service connections should be accounted for and unobstructed. Any defect which will, or potentially could affect the structural integrity or performance of the renewed conduit shall be repaired using means and method approved by the owner before the final acceptance of the product.

### 3.2.4 Close-Fit Pipe

#### 3.2.4.1 Introduction and Background

Close-fit lining involves the insertion of a thermoplastic pipe with an outside diameter the same or slightly larger than the inside diameter of the host culvert. As a result, the liner must be modified in cross section before installation (FHWA. 2005). Close-fit pipes are generated by modifying the cross sectional area of polyethylene pipes, inserting them to the host pipe and returning the cross sectional area to the normal by applying pressure. In this type of renewal, the pipe is manufactured before being brought to the job site, which increases the quality of the finished product.

### 3.2.4.2 Product Main Characteristics

Close-fit pipe trenchless culvert renewal uses a new Polyethylene pipe (PE) that is modified in cross section before it is installed. After placement or insertion in the existing pipe, it is reformed to its original size and shape to provide a close-fit with the existing culvert. Close-fit lining methods can be categorized into two main groups (Figure 3-9) based upon the method used for cross-sectional modification and reformation. These two groups are classified as symmetrical reduction or reduced diameter pipe systems and the mechanically folded systems.

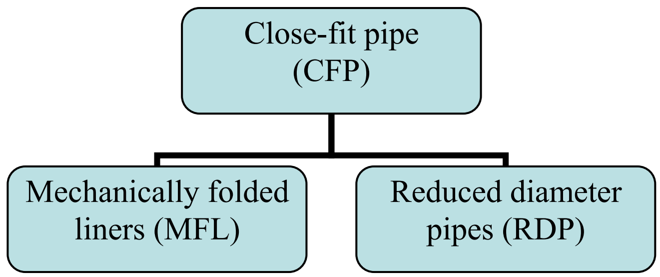


Figure 3-9 Two main divisions of Close-fit pipe process.

Mechanically folded liners requires site-based equipment that cold-folds the liner in a U shape and applies thin plastic straps to restrict the expansion of the liner during installation. A folded and banded liner is winched into the host culvert and rerounded when the binding straps are broken by expanding the liner with internal pressure. Figure 3-10 shows the U shape and the equipment used.

Figure 3-10 Mechanically folded liners equipment and pipe.
(Source: Insifuform Technologies)

Reduced diameter method rearranges the molecular structure of the plastic pipe by the use of a cold rolling machine or by thermal methods (swage). This cold rolling machine applies pressure to the pipe in such a way that reduces the diameter of the plastic pipe without reducing its inherent properties and structural capability. This process is not dependent upon tension or other mechanical means to prevent the liner from reverting to its original size during insertion. Once the diameter has been reduced, a winch is used to pull the liner into place and the liner reverts to its original diameter (FHWA. 2005). Figure 3-11 shows the cold rolldown machine.

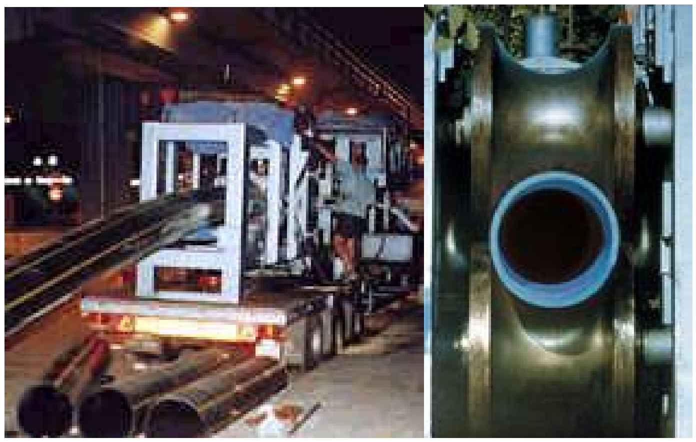

Figure 3-11 Rolldown machine and its action.
(Source: Subterra)

Table 3-4 Main characteristics of Closed-Fit Pipe

| *Diameter range (in)* | *Maximum installation (ft)* | *Grouting* | **Liner material** |
|---|---|---|---|
| **12 - 24** | 1000 | Not necessary | HDPE, MDPE |

### 3.2.4.3 Method Installation Description

The installation of a Close-fit pipe renewal method includes several steps.

i. Site selection, excavation (if necessary) and cleaning (i.e., debris removal) of entry/exit insertion pits.

ii. Inspection, cleaning and preparation of the culvert (including the removal of protruding fittings).

iii. Bypassing of flow is required, unless flow can be shut off during installation.

iv. Preparation and butt fusion of polyethylene liner pipe string and removal of external beads. It should be noted that initial polyethylene liner outside diameter must be greater than the culvert internal diameter to ensure a close-fit after reversion.

v. Feeding the polyethylene pipe through the cross sectional reduction machine (Mechanical folded pipe or Reduced diameter pipe machine). The mechanical folded pipe requires securing with temporary restraining bands.

vi. Insertion of the liner into the culvert. To decrease pulling forces, lubrication before insertion is required.

vii. Seal of the ends of the liner pipe and fill the liner with water.

viii. Apply pressure to the liner pipe to bring it to a close-fit with the existing culvert and hold it for a specified reversion period (usually 12 h).

ix. When finished depressurize and complete the liner end terminations

#### 3.2.4.4 Advantages and Limitations

Advantages of close fit pipe are:

- The new pipe is produced at a controlled environment
- Minimal reduction in the existing pipe area
- Mechanically folded pipes can accommodate 45 degree bends
- Few or no joints
- No grouting is required

Limitations of close fit pipe are:

- The diameter and installation range is limited
- A large working space is needed
- Usually the flow needs to be bypassed
- Existing culvert must be longitudinally uniform (diameter changes or discontinuous culverts may prohibit this method) (FHWA. 2005).
- Relatively complex method requiring special machinery. (FHWA. 2005).

#### 3.2.4.5 QA/QC

A final quality review compares the completed renewal work with the requirements of technical specifications and contract documents. A final review would expose any variations of changes between the contract documents and the work of the contractor.

When a renewal project is completed, the contractor provides the pipeline owner with documentation of the quality of the work performed. In this respect, it is important that requirements for such documentation be included in the bid documents. The documentation should include the following.

- Information on the products and the installation method used.

- Pre and post inspection results.
- Test results
- Any changes or deviations from contract documents and possible corrective work performed
- Information on service lateral reinstatements and pipe ends or manhole connections and possible grouting process performed.
- Recommendations for future inspections, cleaning, maintenance, and other renewal works to be completed as part of a comprehensive renewal work.
- Survey of residents, businesses and customers about the renewal project.

### 3.2.5 Thermoformed Pipe

#### 3.2.5.1 Introduction and Background

HDPE folded pipeline was first installed in 1988, however, as of 2007 production of HDPE folded pipeline has ceased in North America and such products are no longer available to the sewer and drainage rehabilitation market. PVC folded pipe liners were first installed in 1988. Currently there are three manufacturers, which support approximately 40 crews with availability across most of North America.

Folded Thermoplastic (HDPE or PVC) Pipe liners are utilized to rehabilitate small size (30in. and under) culverts. All Folded Thermoplastic Pipe liners share the following common characteristics (ASCE, 2008):

- Cross sectional area is temporarily altered to enable insertion,
- The pipeline is pulled through one access point to the next,
- After insertion, pipe liners are heated and thermoformed to fit tightly inside the old pipe.

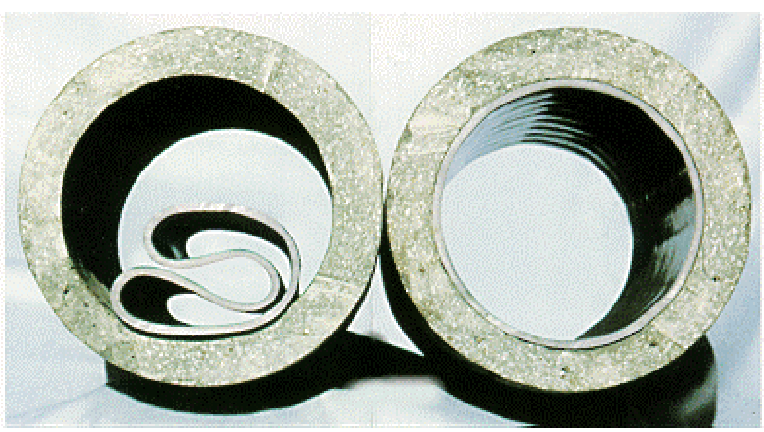

Figure 3-12 Folded Thermoplastic Pipeline (ASCE, 2008).

Over 5,000 miles of Folded Thermoplastic Pipe liners have been installed in the waste water, storm water, and water sectors. Figure 3-12 shows a sample of the thermoplastic pipeline.

### 3.2.5.2 Product Main Characteristics

Folded Thermoplastic Pipe liners are structurally designed according to the ASTM F 1216 design appendix. The design life is generally established as 50 years, but a 100 year performance life is reasonably achievable with adequate conservatism in design choices. The different size ranges, maximum lengths, and materials of Thermoformed pipes are listed in Table 3-5.

Table 3-5 Main characteristics of Thermoformed Pipe

| *Diameter range (in)* | *Maximum installation (ft)* | *Grouting* | **Liner material** |
|---|---|---|---|
| **12 - 30** | 1500 | Not necessary | HDPE, PVC |

The flow capacity of a deteriorated culvert can be significantly reduced by the deterioration of the invert and by the resulting debris and silts collected. The culvert preparation and pre-cleaning process will frequently restore most of the original design flow capacity. Thermoplastic PVC pipe liners are highly corrosion and abrasion resistant and are not subject to comparable flow deterioration over time.

The PVC materials have a material Manning's coefficient of approximately 0.009, although the effective Manning's coefficient is expected to be higher due to conformance to the host pipe geometry. The enhanced surface smoothness after lining can significantly increase the flow speed, thus reducing future debris and silts deposition. Although the pipeline will slightly reduce the culvert inside diameter the increase in flow rate will result in no loss of flow capacity. Even though it is generally not the primary reason for culvert lining, the increased flow rate resulting from lining can be significant. As a result, project engineers should be cautious to consider the prospects of downstream scouring after lining and to include additional outlet modifications as needed (ASCE, 2008). The installation of Folded Thermoplastic Pipe liners is generally not precluded by steep slopes or narrow catch basins; such site conditions do not alter any of the design properties of a Folded Thermoplastic Pipeline.

### 3.2.5.3 Advantages and Limitations

Advantages of thermoformed pipe are:

- The new pipe is produced at a controlled environment (factory) therefore quality is higher and installation is fast.

- The cross sectional reduction is minimal, thus minimal or no reduction in flow capacity.
- It can provide a design life of a new pipe.
- Few or no joints.

Limitations of thermoformed pipe are:

- Diameter range is limited.
- Bypassing the existing flow is required in many cases.
- Large working space may be required for some type of installations.
- Liner lengths are limited by pull-in forces or coil lengths. (FHWA. 2005).

### 3.2.5.4 Method Installation Description

In this type of renewal, polyvinyl chloride or polyethylene pipes are thermoformed inside the host pipes to provide a tightly fitting chemical and abrasion resistant pipe. In order to insert the new pipes they are either “deformed and reformed”, “fused and expended” or “fold and formed”.

i. “Prior to pipeline installation, the culvert needs to be properly cleaned and prepared, with a final cleaning and inspection to be completed while the pipeline is pre-heating. Proper cleaning should include de-rooting (if applicable), repairs to missing or damaged inverts, and removal of debris or deposits in the culvert. If roots or deposits or rocks in the invert are lined over, the pipeline will conform to them. Missing inverts should generally be repaired; the pipeline can be expected to “belly” into any unfilled voids in the invert, thereby increasing the likelihood of future siltation in the lined culvert” (ASCE, 2008).

ii. Bypassing may be required prior to pipelining. Once all site preparations have been completed, the pre-heated pipeline is pulled through the existing culvert pipe by means of a winch cable extending to a distant access point.

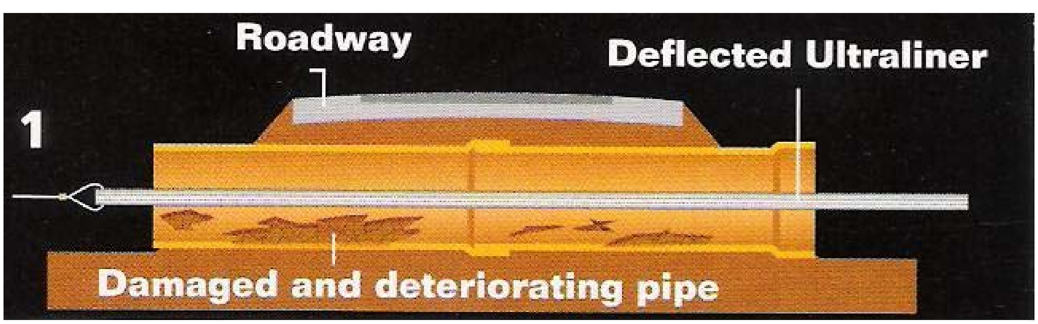


Figure 3-13 The Folded Thermoplastic Pipeline is pulled through the deteriorated culvert (ASCE, 2008).

iii. After pipeline insertion, a flow-through plug is then inserted into the pipeline at the boiler end and steam is sent through the lumen of the pipeline to relax it from the axial forces of the insertion pull. During this “relaxation period” some “stretch” of the pipeline may relax. The tougher the pull, the longer the required relaxation period will be. Once the pipeline has dimensionally stabilized, the pipeline can be cut to length, and hydrophilic gasket end seals positioned if they are to be used. The pipeline is then plugged at both ends (see Figure 4-11). [Note: the plugs should be carefully braced or otherwise secured. If a plug fails, the plug can release with deadly force. No personnel should position themselves within the potential path of a plug while the pipeline is pressurized.] Steam is then reintroduced into the lumen to process the pipeline.

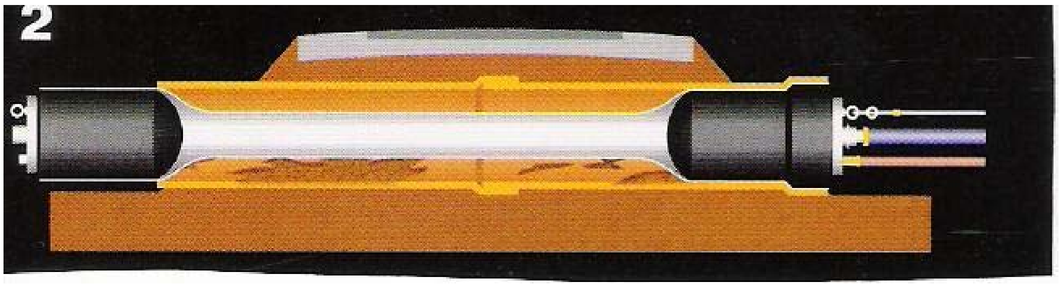


Figure 3-14 After plugging both ends, the Folded Thermoplastic Pipeline is ready to be processed (ASCE, 2008).

iv. As the pressure rises inside the pipeline, the pipeline begins to round and then expand so as to thermoform the pipeline tightly out against the culvert pipe. The pipeline will conform to the exact geometry of the host pipe. If a corrugated pipe is lined, the pipeline will likewise become corrugated as seen in Figure 3-15. As pressure rises, so does the temperature; thus during processing of the pipeline air is blended with the steam to prevent the temperature from spiking too high. Processing temperatures will generally be in the 210° F to 220° F range.

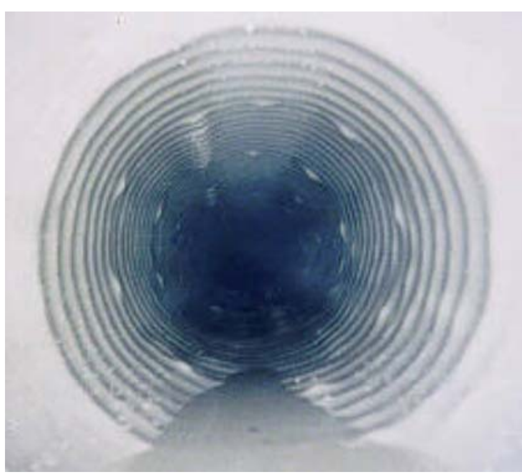

Figure 3-15 A lined corrugated pipes with rivets clearly visible through the pipeline wall (ASCE, 2008).

v. Once the pipeline has "belled" past the diameter of the host pipe in the downstream access point, steam is discontinued, but the pressure is raised with an increase of air flow to keep the pipeline out tight against the host pipe. Cooling the pipeline under pressure substantially precludes shrinkage from the material's coefficient of thermal expansion (CTE). As the pipeline cools, a chiller is used to refrigerate the air to more fully cool the pipeline. The cooler the pipeline is at the time of depressurization, the tighter the pipeline will fit. When below at least 100 degrees F, the flow-through plugs can be pulled (ASCE, 2008). The final Thermoplastic pipeline is shown in Figures 3-16 and 3-17.

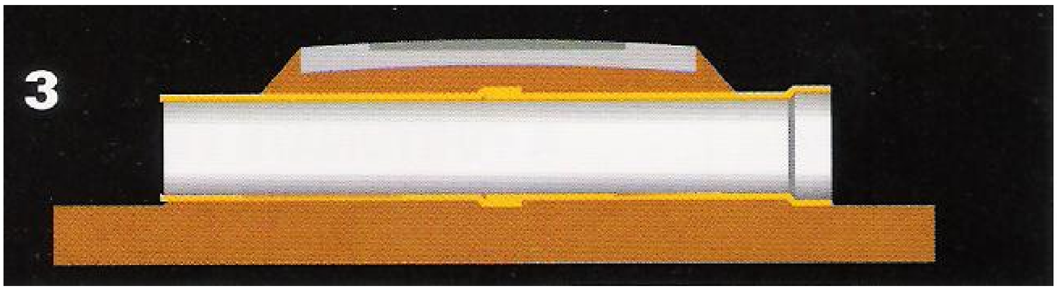


Figure 3-16 The Folded Thermoplastic Pipeline fitting tightly inside the deteriorated culvert (ASCE, 2008).

vi. Immediately after the pipeline processing and cool down are complete, the construction crews should send a camera through the full length of the pipeline to confirm proper installation. Ends should not be trimmed until a full-length inspection has been completed. Prior to trimming the ends, if need be, a pipeline can be more simply reprocessed or else, if seriously damaged or failed, re-heated, collapsed and removed.

vii. Subsequent to cooling and initial post-installation inspection, the ends are trimmed to length.

Figure 3-17 An example of a culvert renewed with a Thermoplastic pipeline (ASCE, 2008).

#### 3.2.5.5 QA/QC:

Folded Thermoplastic Pipe liners are pre-manufactured. The required quality control protocols of the ASTM product standards verify the pipe-liner's compliance with wall thickness, material modulus, corrosion resistance, and other long-term structural design requirements within the controlled environment of the manufacturing facilities. The field installation process, including variable field conditions and crew decisions, does not and can not influence the structural design compliance of a Folded Thermoplastic Pipeline. Compound suppliers, manufacturers, and technology providers perform essential roles in the QA/QC of Folded Thermoplastic Pipe liners. The construction crews have a negligible influence upon the pre-manufactured pipe-liner's design properties and can do very little to subvert quality assurance.

The compound supplier is responsible for testing every blended "lot" of compound for either the flexural modulus and flexural strength or the tensile modulus and tensile strength according to the referenced ASTM standards. The technology supplier's production request to the manufacturer should include the following information:

- Confirmation #
- Customer (Installation Contractor)
- Project Manager/Project Engineer (Consultant/Agency)
- End-User (Agency/Owner)
- Manhole or Access Point #
- Nominal Size of the pipeline
- Extruded O.D. (sleeve size) of the pipeline
- Nominal Wall Thickness (the wall thickness after expansion to the nominal size)

The manufacturer, in order to comply with the applicable specifications and standards, is generally required to clearly mark the following information at 5ft intervals or less:

- "Brand Name"
- Date
- Shift
- Nominal Pipe Size
- Cell Classification
- The legend "DRXX Folded Pipe" (where XX designates the nominal DR)
- The designated ASTM specification to which the material complies
- The approximate coil length

The following information should be recorded during production:

- Operator's Name

- Resin Batch # and Production Lot #
- Shift
- Date and Time
- Pipe Diameter Measurements (ASTM D 2122)
- Additional comments by the operator

The following information should be gathered and recorded by the QA/QC personnel:

- Wall Thickness measurements at the end of the reel
- Internal Cosmetics
- External Cosmetics
- Additional Comments
- Overall (pass or fail)

Samples should be collected from the beginning and end of every reel produced. From a portion of these samples the following tests should be run, in order to comply with the applicable specifications and standards:

- Impact resistance (ASTM D256 & D 2444)
- Flattening to 60% (ASTM D 2412)
- Pipe Stiffness at 5% Deflection ( ASTM D 2412)
- Acetone Immersion (ASTM D 2152)
- Heat Reversion (ASTM F 1057)
- Tensile Strength (ASTM D 638)
- Flexural Modulus (ASTM D 790)
- Overall (pass or fail)
- Signature of QA/QC Inspector

### 3.2.6 Panel Lining

#### 3.2.6.1 Introduction and Background

In 1979, Water Research Center (WRc) in the United Kingdom was commissioned by the government and several other companies to undertake a 5-year research in methods and materials for structural renewal of large-diameter noncircular sewers. The US$18 million contract was complemented in 1984 and the WRc's manual on sewerage rehabilitation design was published. This procedure certainly can also be used to renew culverts and/or drainage structures that have noncircular cross sections. Noncircular sections as pipe arch or elliptical, box sections or multiple barrels; also explained in section "1.11.1 Culvert Classification by Shapes". Panel lining technique can be designed either as a self-supporting pipe or as a pipe, which depends on the strength of the existing pipe and the concrete fill in the annular space. In this type of renewal workers enter the pipe and install the panels manually.

### 3.2.6.2 Product Main Characteristics

Many systems for renewing large-diameter pipes are currently available. One of these methods is fiberglass liner, also called fiberglass reinforced poly ester panel (FRPP), manufactured as pipe segments or panels. Glass-fiber liners can be manufactured to fit any size or shape. The main structure of the liner and its make-up wall incorporates a corrosion barrier on the inside surface followed by a layer of preformed, powder bound, chopped strand glass mat consolidated with isophtalic resin. Figure 3-18 represents an egg-shaped fiberglass liner.

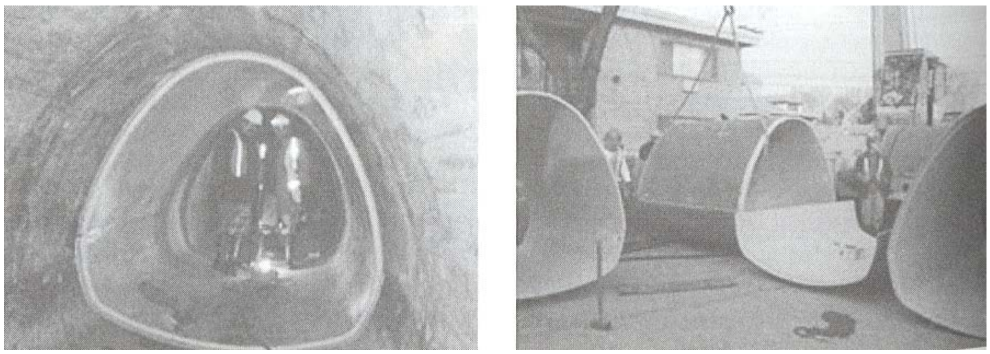

Figure 3-18 Channeline fiberglass panels.
(Source: Kenny Construction Company)

The liner pipes are made of various combinations of fiberglass mats, glass fibers, polyester, vinyl ester, epoxy resin, and sometimes silica sand. When the liner pipes are machine-made, a 0.1 in. (approximately 2 to 3mm) thick fiberglass mat is laid first and then impregnated with polyester to form a corrosion-resistant layer. Subsequently, the mould is rotated while polyester-soaked fibers are spun on. Fine silica sand is sometimes applied at the same time as the fibers. The process is continued until the required wall thickness is achieved.

Table 3-6 Main Characteristics of Panel Lining

| *Diameter range (in)* | *Maximum installation (ft)* | *Grouting* | **Liner material** |
|---|---|---|---|
| **42 in. and larger** | N/A | Cementitious or polymer | PVC |

Panel liners can be designed and constructed as self-supporting, flexible pipes. Alternatively, strength can be achieved by sandwiching together the existing pipe, the liner, and the concrete filling the annular space between the two. Different design criteria are used in different parts of the world. Where there are no national standards, guidelines from the WRc in the United Kingdom as described previously are often used.

### 3.2.6.3 Advantages and Limitations

Advantages of panel lining:

- Panel lining can be used in any shape of pipe.
- Chemical and abrasive resistant liners can be installed.
- It can be installed under restricted flow conditions.
- Changes in pipe diameter can be negotiated with prefabricated transition panels.

Limitations of panel lining are:

- Only worker entry pipes can be renewed by this method.
- Grouting must be applied to the annular space.
- Reductions in the cross sectional area may be significant.

### 3.2.6.4 Method Installation Description

i. Before starting the renewal project, it is important to carry out a detailed preliminary survey of the project site, inspection and cleaning of the culvert.

ii. Some preparatory work issues must be attended such as, measuring of the existing culvert internal diameter at different locations, cutting roots if necessary and sealing leaks to prevent groundwater infiltration.

iii. Panel lining has the advantages that flow bypassing is not always necessary. Flooding usually does not damage work in progress, however, safety of workers inside the culvert must be considered.

iv. A crane should be positioned above the launch pit to lower panels to the culvert entrance. There should also be a compressor, a generator as well as tool storage and personnel facilities.

v. Manually position each prefabricated fiberglass pipe segments. Most panel liners are machine-made as centrifugal-cast or spun sections. Panel liners usually have tongue and groove joints that are sealed with either rubber sealing rings or polyurethane or epoxy filler. Liner segments have specially developed longitudinal joints that are sealed with epoxy filler. Panel installation usually starts at the opposite end of the existing pipeline so as to finish at the entry-pit.

vi. Once the panels have been positioned throughout the length of the pipeline the annular space is filled with structural grout. Care must be taken during the pumping process to prevent the panels from being subjected to excessive external pressure. This is accomplished by checking the pump pressure and the floatation forces that the panels are subjected to by the fluid concrete.

### 3.2.6.5 QA/QC

During the installation, certain safety and quality requirements must be met. OSHA's safety regulations for confined-space entry must be addressed by a competent person. After installation it is often necessary to carry out the completion work by conducting a final inspection and leak testing. Also notifying residents and businesses about work completion and conducting a public survey for improvements in future projects is usual.

## 3.2.7 Formed-in-Place Pipe

### 3.2.7.1 Introduction and Background

The Formed-in-Place Pipe (FIPP) technology, which utilizes anchored HDPE panels, was developed in Germany in the early 1990s. Since 1992, FIPP has been widely used with over 1 million linear feet installed around the world, including projects on five continents. The essential component of the FIPP rehabilitation technique is the HDPE panel with V-shaped embedment anchors (see Figure 3-19). The annular void created by the anchors is filled with high strength grout. The grout fixes the HDPE panels permanently in place. The grout and the embedded HDPE anchors function as a composite structure and provide the load bearing capacity. (ASCE, 2008)

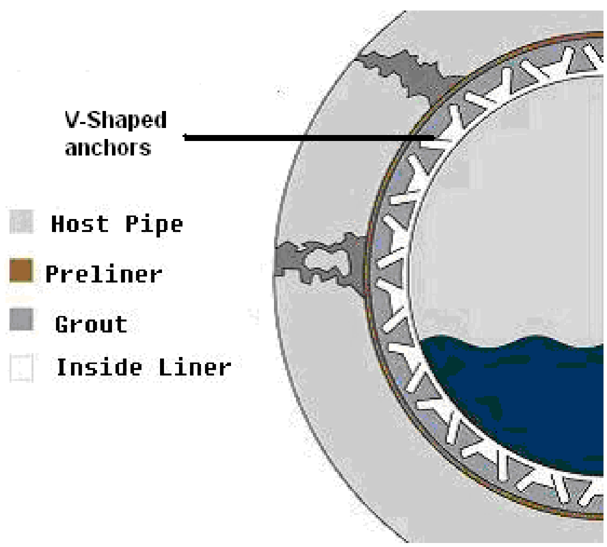


Figure 3-19 Formed-in-Place Pipe cross section (ASCE, 2008).

### 3.2.7.2 Product Main Characteristics

The HDPE panels are made of high-density ethylene/octane copolymer resin. Depending on the specific jobsite condition, a pre-liner will typically apply. The pre-liner is made of the same material, but is smooth on both sides. The inside liner is manufactured with embedded anchors on its outer surface as shown in Figure 4-16. The anchors are available in heights of 0.394 inches (10mm), 0.512 inches (13mm), or 0.748 inches (19mm). The HDPE panels used to make the inside liner are homogenously extruded with the anchors as one piece with a minimum of 39 anchors per square foot of panel.

The portion of the HDPE panels exposed at the ends of the culvert must contain UV protection such as carbon black. The translucent panels typically used for sanitary sewer rehabilitation do not provide suitable UV protection for the exposed ends of culvert applications, and if they are to be used, will require the application of additional UV protection measures at the culvert ends.

The grout utilized with the FIPP technology is a low-viscosity, quick and ambient-curing, expansive, cementitious polymer mortar of high strength. The 28 day compressive strength of the cementitious grout exceeds 10,000 psi. The HDPE FIPP technology essentially forms a polyethylene encapsulated cementitious pipe tightly inside of the old culvert pipe.

HDPE panels are coiled on reels and the grout is bagged for shipping and storage convenience. On site, the HDPE panels can be stored outside within manufacturer recommended temperatures. In case of temperatures outside this range, special measures should be taken inside a warehouse, controlled climate trailer, or other storage facility. As a quality control precaution, storage of the HDPE panels and tubes under direct solar radiation is not permitted; this is of particular importance for the translucent panels which do not contain UV protection. The HDPE panels must always be covered with a suitable protection after delivery to the site. The grout must be stored under dry conditions at manufacturer recommended temperatures. With proper storage, the pipeline tubes are warranted by the manufacturer as shelf-stable for a period of one year after production and are expected to remain shelf-stable thereafter.

The HDPE FIPP installation and design are governed by existing European standards with ASTM standards under development. The design life is for 50 years at minimum with high corrosion and abrasion resistance, while providing independent structural integrity. Figure 3-20 shows some of the cross sectional shapes in which FIPP can be used.

Figure 3-20 Using of FIPP in different culvert shapes (ASCE, 2008)

Table 3-7 Main Characteristics of Formed-in-Place Pipe

| *Diameter range (in)* | *Maximum installation (ft)* | *Grouting* | **Liner material** |
|---|---|---|---|
| **8in. to 120in. and larger** | 600' (up to 40in.)<br>400' (up to 50in.)<br>200' (up to 80in.)<br>Note: A. | Cementitious polymer mortar | HDPE |

Note A. Any length of continuously welded pipeline is possible, but must be installed with interim grout ports as per the above maximum lengths.

### 3.2.7.3 Advantages and Limitations

Some of the advantages that this technique provides are listed as follows:

- FIPP can be used in any shape (circular, oval, vertically sided, symmetrical, or nonsymmetrical).
- FIPP can serve for both corrosion control and structural purposes.
- FIPP can be used for long-drive length where access is limited.
- Nonstandard shapes up to 12 ft in diameter are possible.
- There might be an improved hydraulic capacity by providing a lower coefficient of friction.
- FIPP is abrasive resistant and chemical resistant, excellent in corrosive environments.

Limitations

- Significant reduction in cross-sectional area of the culvert is possible.
- Access shafts or great clean out process may be required.
- The annular space must be grouted.

### 3.2.7.4 Installation Process

Prior to pipeline installation, the culvert needs to be properly cleaned and prepared, with a final cleaning and inspection to be completed during preparations for pipeline insertion. Proper cleaning should include de-rooting (if applicable) and removal of debris or deposits in the culvert.

Water flow must be temporarily stopped, by-passed, or diverted during the FIPP installation. Once all site preparations have been completed, the pre-liner is pulled through the existing culvert pipe by means of a winch cable extending to a distant access point. The pre-liner is then provisionally inflated with compressed air and tested for leak tightness. Each anchored inside liner is then pulled through the lumen of the pre-liner (ASCE, 2008).

Figure 3-21 Insertion of the anchored liner (ASCE, 2008).

After insertion of all pipeline tube layers as specified in the design, the annular space between them (as established by the height of the anchors) is sealed at both ends by PE extrusion welding techniques (see Figure 3-22). Because the grout is injected into the sealed annulus between the pipeline layers, bulkheads are not required.

Figure 3-22 Extrusion welding of the HDPE FIPP ends (ASCE, 2008).

Grouting ports are connected to the void space(s) at the downstream access point as seen in Figure 3-23, while air release ports are connected at the upstream access point. Smoke testing is used to check the air tightness of all welds and of the pipeline walls prior to grouting. In man-entry sizes, if tube leaks occur, they can be readily repaired in situ with welding techniques.

Figure 3-23 Attachment of grouting ports (ASCE, 2008).

Once confirmed to be leak free, the pipeline tubes are ready for forming. Smaller size pipe liners (30in. and smaller) can be plugged and pressurized to conform to the host pipe with either air or water (see Figure 3-24). Water pressurization is generally preferred for culverts larger than 30in., despite the increased cost and potential water wastage, because water is less compressible than air and therefore considerably safer. A water column is generally used for water pressurization in order to more readily control the pressure consistency. The pipeline is pressurized internally to keep the pipeline formed tightly against the host pipe while off-setting the grout pressure.

Figure 3-24 Plugging of the HDPE FIPP ends (ASCE, 2008).

For culverts larger than 80in. in diameter, or of irregular geometry, the use of formworks, instead of pressurization, is generally required for various constructability reasons. Where form works prove to be advantageous, the technique can be used in any man-entry diameter pipe (generally 42in. and larger). A sample image of the formwork is illustrated in Figure 4-22. The form works must be structurally sufficient to withstand all short-term loads including the grout. Although grouting in lifts has increased labor and installation time disadvantages, there can be cost advantages from the reduced structural requirements for the form works. Such considerations must be weighed on a case by case basis (ASCE, 2008).

Figure 3-25 Installation of form works in preparation for grouting (ASCE, 2008).

The use of formworks avoids the use of high volumes of pressurization water, which is frequently not readily accessible at remote culverts, or is prospectively environmentally unacceptable. The use of form works has the added advantage of potentially reducing the duration of by-pass pumping. On the other hand, forming the pipeline by pressurization has the advantage of eliminating or at least reducing the need for man-entry and also significantly reducing set-up labor costs and overall time of construction. Once again, such considerations must be weighed on a case by case basis.

Once the pipeline tubes have been formed against the host pipe and structurally supported by pressure or formworks, the grouting process can begin. The required grout quantity can be estimated by the fixed volume of the anchor defined annulus. The sealed annulus within the pipeline layers precludes environmental contamination by grout leakage, and ensures consistent grout strength through controlled water to grout mixing ratio. Only potable quality water should be used for grout mixing. A sufficient quantity of grout mixing units will be required to ensure that the estimated quantity of grout can be injected. Figure 3-26 shows various grouting mixing units.


Figure 3-26 Small scale and large scale grout mixing set-ups (ASCE, 2008).

In order to avoid trapping air, the grout is generally introduced by gravity column and allowed to flow from the lower end of the culvert upwards. The length which the grout can be flowed will be influenced by the slope of the culvert, the volume of grout that can manage to be mixed and injected during the allotted grout flow period, and the diameter of the pipeline. Estimated maximum grout flow lengths are provided in Table 3-7 In longer length man-entry applications, where interim grouting ports are not possible, alternative installation methods including grout pumping have been utilized, but increase the risk of void formation and require additional quality control considerations. After complete grouting (Figure 3-27) of the HDPE FIPP section, the grout must be allowed to cure, generally over night. The forming pressure or form works cannot be removed until the grout is cured.

Figure 3-27 Completed HDPE FIPP installation (ASCE, 2008).

#### 3.2.7.5 QA/QC

The wall thickness and corrosion resistance of HDPE FIPP is unalterably established during the pre-manufacturing of the HDPE pipeline panels. However, the FIPP culvert rehabilitation technique is still largely a field manufacturing process, which is inevitably subject to variables which may affect the quality of constructed culvert pipe liners. Besides the QA/QC procedures at the manufacturing facilities of the HDPE panels and the grout, QA/QC at the construction site is essential to control the influence of field variables and to provide the customer with the best quality product as constructed.

The following inherent technology advantages facilitate the QA/QC of FIPP pipe liners:

- The minimum thickness of the pipeline is the height of the embedded anchors and is unalterable by field conditions or by construction crew decisions.
- The grout is injected into the sealed annulus between the layers of the pipeline using a gravity column, instead of pumping; this tends to preclude the creation of grout voids inside the pipeline.
- The required volume of grout necessary to achieve the structural wall thickness requirements is established and controlled by the fixed, sealed annulus between the layers of the pipeline.
- The application of the pre-liner prevents the grout from escaping, washing away, or losing strength due to dilution by ground water.
- The weld quality and the water-tightness of the HDPE FIPP are confirmed during the installation process.

Because critical structural design properties of a HDPE FIPP are established during field manufacturing, additional field quality tests are essential before and during the grouting process to ensure that design values are being achieved under varying field conditions. With HDPE FIPP, design compliance is monitorable and confirmable during installation. Required field quality tests (see Figure 3-28) of the structural grout include: viscosity, weight, water-cement ratio, temperature, and material expansion (ASCE, 2008).

Figure 3-28 Viscosity, weight, water-cement ratio, temperature, material expansion, and strength tests (ASCE, 2008).

Because temperature, humidity, and other field conditions routinely vary as the installation progresses, the field crews are required to make adjustments to maintain the water-cement ratio of the grout in order to maintain specification compliance. By maintaining tolerances throughout the installation process, the specification compliance and consistency of the HDPE FIPP can be confirmed down the full length of the installed pipeline. Conformance of these material property requirements during field manufacturing should also ensure that the post-construction strength tests of grout beam samples will also comply with the specification requirements and be reliably representative of the full length of the as-constructed HDPE FIPP.

Voids are not known to form with such low viscosity grout (prior to curing it flows like milk) which is injected by gravity column from the low end to the high end of the culvert. With the translucent HDPE panels, an internal visual inspection, even by CCTV, can confirm the lack of voids in the grout. For man-entry sizes, a “tapping test” can confirm the lack of voids behind an opaque HDPE panel.

### 3.2.8 In Line Replacement

#### 3.2.8.1 Introduction and Background

In-line replacement technology originated in the 1970s and it is most cost-effective if a new culvert with a larger diameter is required. Virtually all types of culvert materials can be replaced using this technique, the new pipe material can be PE (Polyethylene), PVC, ductile iron, and vitrified clay. The In Line Replacement technique can be divided into two main categories of pipe bursting and pipe removal and they can be further divided into different methods (see Figure 3-29). Is encouraged to the reader to find further explanation of the divisions of pipe bursting and pipe removal in the reference number 52.

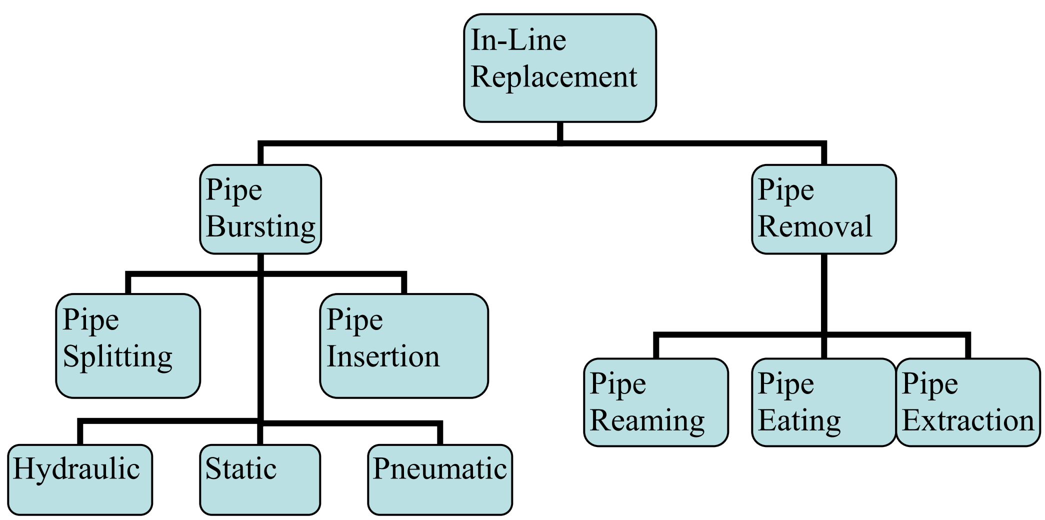


Figure 3-29 Categories of in-line replacement methods (Najafi, 2005)

#### 3.2.8.2 Product Main Characteristics

In a typical pipe bursting operation, a cone-shaped tool (bursting head) is inserted into the existing culvert and forced through it, fracturing the pipe and pushing its fragments into the surrounding soil. At the same time, a new pipe is either pilled or pushed (depending on the type of new pipe) in the annulus left by the expanding operation. The rear of the bursting head is connected to the new pipe, and the front end of the bursting head is attached to either a winching cable or a pulling rod assembly. The bursting head and the new pipe are launched from one of the ends of the culvert. The cable or rod assembly is pulled from the pulling or reception area at the other end of the culvert.

Pipe removal (also known as pipe eating) is a replacement technique, which is based on horizontal directional drilling (HDD) technology or microtunneling (MT) technology. This method excavates the existing pipe in fragments and removes them rather than displacing them into the surrounding ground (as pipe bursting does). Pipe removal is divided into piper reaming, pipe eating and pipe ejection or pipe extraction.

The subsurface conditions must be thoroughly investigated for suitability of in-line replacement methods. For example, when pipe bursting is used below the water table or when the existing culvert is surrounded by sand, the pneumatic pipe burster can create a vacuum that prevents progress. This problem can be solved by lowering the water table or by using other pipe bursting methods, such as static heads which advance solely on high pulling forces without the use of pneumatic actions.

Table 3-8 Main Characteristics of In-Line Replacement

| *Diameter range (in)* | *Maximum installation (ft)* | *Grouting* | **New material** |
|---|---|---|---|
| **8 to 48** | 300 to 400 | Not required | PE, PVC, Ductile Iron, Vitrified clay |

### 3.2.8.3 Advantages and Limitations

The main characteristic and advantage of the In-Line replacement method is that not only the replaces an equivalent sized line but also upsizes the existing culvert or storm sewer. Another important advantage is that the method does not require much of the preparatory work -pipeline cleaning, root cutting, cutting of displaced joints, and so on- required by other renewal methods.

Some other advantages are:

- A wide range of existing pipe types and diameters are possible to replace.
- The new pipe will follow the alignment of the existing culvert.
- In pipe bursting, the existing culvert is left underground eliminating the need for its disposal.

Limitations of in-line replacement:

- Bypassing of flow is usually required.
- Ground movements, vibrations, and possibility of damaging nearby utilities and existing structures must be evaluated for specific conditions of each project.

- There is a risk of disturbing the pavement surface above the existing culvert.

### 3.2.8.4 Installation Process

#### 3.2.8.4.1 Pipe bursting

Pipe bursting is accomplished by the advancement of a cone-shaped bursting head through the host culvert; due its geometry the bursting head translates forward thrust into radial expansion forces. These radial expansion forces overcome the original culvert's tensional and shear forces strength capabilities and subsequently bursts or splits it. Attached to the rear of the bursting head is the new culvert pipe, which is simultaneously installed as the bursting head advances and bursts the host culvert. This technique has been used to replace cast iron, clay, reinforced concrete, polyvinyl chloride (PVC), high-density polyethylene (HDPE), and ductile iron pipes. Therefore, it should work as well for culverts with similar materials. Typically, HDPE pipe is the material of choice as the replacement line, though clay, concrete, PVC, and steel pipe can also be used for either continuous or sectional installations (Lueke & Ariaratnam 2001).

As a general rule, the pipe bursting project is subdivided into sections or lengths that the specific equipment being used can burst based on the geometry and layout of the total length of culvert being replaced. The length of the culvert that can be replaced in a section is dependent on the type of pipe being burst, degree of upsize, soil conditions, geometry of the original installation, and the type of bursting equipment and method used. In addition, the new pipe, whether it is continuous or sectional, will dictate the type of equipment required and the pit setup (Lueke & Ariaratnam 2001).

For the installation of continuous culvert, such as HDPE (high density polyethylene), or steel, access pits must be excavated at each end of the culvert to be replaced if necessary. In general, pipe bursting installations for culverts might not need excavation of pits because most of the times culverts resides below the pavement of the roads and can be accessed by the embankments. Nevertheless, some times it will be possible to encounter debris or the like, which requires a clean out process. On one end of the culvert, a pulling machine is set up and on the opposite end the bursting head and the new pipe are inserted. The pulling machine drives the combination of bursting head and pipe through the host culvert. In this case, the pulling mechanism could consist of rods, chain, or cable.

A slightly different setup is required if sectional non-welded joint (clay, PVC, or reinforced concrete) culvert is used to replace the existing one. Again access pits are excavated if required or cleaned at the minimum at each end of the culvert. In this case both ends are considered machine pits. The installation of sectional culvert requires that constant force be applied to the pipe to keep the joints together during installation. This may be achieved by using a chain or cable run through the new culvert from the bursting head to a trailing plate on the last culvert section, or alternatively by using a pus-pull technique. In the push-pull setup, the bursting head would be pulled by one machine in the pulling pit, while in the opposite pit, the culvert section would be pushed by another machine. In this setup, a constant pressure is applied to the new pipe during installation by maintaining the push force slightly higher than the pulling force; to achieve this set up on site arrangements may be necessary to accommodate the pushing equipment on the embankment of the road. Please be advised that the last two installation procedures are just for illustration purposes and are limited only to the static subdivision of pipe bursting. More information about installation procedures using other subdivisions can be found in the reference 52.

#### 3.2.8.4.2 Pipe Removal

In general, pipe removal differs from pipe bursting in that the surrounding soil is not compressed as the bursting head advances; pipe removal rather eats or removes the soil and the host culvert material. The system provides for the removal of existing vitrified clay pipe (VCP), PVC, asbestos cement (AC), or nonreinforced concrete culvert and simultaneous replacement with a high density polyethylene (HDPE) or PVC culvert of equal or larger diameter. Usually double diameter replacement is the practical maximum upsize. Removal of the existing culvert is accomplished by either back reaming, microtunnel boring machines or by ejecting the culvert.

Pipe reaming is a modified back reaming method used in directional drilling systems, which is specially adapted for culvert replacement, pipe eating is a modified microtunneling system specially adapted for pipe replacement, and pipe ejection and pipe extraction are pipe removal systems, in which the unbroken existing pipe is removed from the ground, while the new pipe is simultaneously installed.

### 3.2.8.5 QA/QC

When assuring the quality of a project, guidelines where the potential for subsidence (loss of ground) and risks are high should be followed.

The amount of risk depends on the contractor’s experience in addition to a number of factors that require engineering judgment such as: depth of cover, diameter of culvert, proposed methods, soil materials (cohesionless sands, gravels, and cobbles or boulders below groundwater surface are probably the worst) and potential obstructions.

In house designs should consider the following four categories. Depending on the complexity, it may necessary to hire a consultant to perform the design:

i. Geotechnical investigation

ii. Settlement, surface bump and bust, monitoring

iii. Contractor submittals

iv. Contract inspection

Items 2 and 3 should be addressed in the plans and specifications and should be based on the results of item 1.

## 3.2.9 Underground Coatings and Linings

### 3.2.9.1 Introduction and Background

Coatings and linings have been used to renew water and sewer infrastructure for decades, however, they can also be used to renew culverts and storm sewers. Shotcrete, an air-assisted spray-on lining method for cementitious products, was developed at the dawn of the 20$^{th}$ century in Allentown, Pennsylvania, and became accepted as a construction method in 1910. Today, high-tech polymer coatings and composite lining methods are used to restore, protect, repair and renew a wide range of concrete, masonry, and steel structures. These techniques are used to protect existing culverts from corrosion and repair small point leaks.

Reinforced spray mortars are effectively used for man-entry culverts; non-man entry culverts require the lining to be applied with a centrifugal lining machine. Lining material (cement mortar or epoxy) is pumped to the high-speed rotating application head of the centrifugal lining machine. As the machine moves through the culvert, a uniform thickness liner is applied. This monolithic layer that inhibits further deterioration is the principal objective of a coating or lining application.

### 3.2.9.2 Product Main Characteristics

Coatings and linings may be applied to renew and protect aging culverts to increase their service life. The primary materials used for coatings and linings fall into four broad categories of cementitious, polymers, sheet liners, and cured-in-place liners. These methods are sometimes used in conjunction with one another.

In conjunction with chemical resistance and monolithic coverage, adhesion is generally regarded as a required attribute of coatings. Other attributes vary greatly between polymer and cementitious coatings, the most prevalent types used in underground infrastructure protection and renewal. Some may be excellent for bridging moving cracks in concrete structures but may have low chemical resistance owing to inherently higher porosity; others may exhibit excellent long-term strength but poor adhesion in damp environments. As for any renewal method, true project needs should be evaluated and matched with proven product attributes.

Moisture can weaken a coating’s curing processes well as its ability to bond to the existing structure. Although moisture is relatively easy to mitigate in above-surface structures, it cannot be completely avoided below grade, specially in concrete and masonry structures. Therefore, a coating with high moisture tolerance offers an adhesion advantage for below-grade coatings projects. Epoxies can generally be formulated to offer the best moisture tolerance, although some urethanes and urea also offer moderate tolerance or require the use of an epoxy primer. Other attributes to analyze include structural enhancement, permeability and chemical resistance, quick return-to service, maintenance and visibility.

General characteristics of coatings and linings are presented on

Table 3-9 Main Characteristics of Underground Coatings and Linings

| *Diameter range (in)* | *Maximum installation (ft)* | *Grouting* | **New material** |
|---|---|---|---|
| **8 to 177** | 1400 | Not required | Cement-mortar or polymers |

### 3.2.9.3 Advantages and Limitations

Some of the advantages that this technique provides are listed as follows:

- Variations in cross section can be readily accommodated.
- Relatively low cost for cement-mortar lining.
- Quick installation, thus higher production in polymers.
- Polymers do not wear for longer life.
- No pH effect for polymer coatings.
- Protects against corrosion.
- Some reinforcement can be used.

However its limitations may include:

- Relatively slow installation for cement-mortar lining.
- Requires safe conditions for worker entry.
- High-level operator skill is required.
- Water pH sensitive for cement-mortar lining.
- Control of infiltration is required to prevent procure lining disbondment or collapse
- Slightly higher cost when using polymers.

### 3.2.9.4 Installation Process

The application of any coating or lining requires surface preparation. It is necessary to clean and profile the substrate prior to application. Also, most protective materials require that all active infiltration be stopped prior application and some require a dry surface to attain long-term adhesion to the existing structure. Coating systems can be either machine or hand applied. Small diameter (<36 in. ID) culvert applications are generally carried out using spin-cast equipment, a rotating head that is winched trough the pipeline. Large-diameter applications can also be robotically applied or, more likely, installed with hand-held spray equipment.

The objective of surface preparation is to provide a clean, sound surface with adequate profile and porosity that is essential to ensure proper adhesion. Proper site inspection is important to be able to specify the right coating product and appropriate thickness. Because of the "out-of-sight, out-of-mind" nature of culverts and storm sewers, there are always unanticipated difficulties, ranging from active I/I to the presence of various contaminants, which makes the task of coating application rather difficult hence the strong need for professional, experienced applicators.

Non-worker entry culvert cleaning techniques can include robotic low-and high-pressure water jetting, scraping, pigging, rack-feed borers, and mechanically driven devices such as cutters and chain flails. There is often a balance to be drawn between removing all traces of corrosion and avoiding damage to the pipe wall, and some of the more aggressive techniques should be used with caution. Pipe scrapers are designated to remove hard deposit sand nodules when winched through a culvert, and consist of a number of spring steel blades mounted on a central shaft.

Once the culvert is cleaned the installation of the product must begin. In each application, the material is applied in one or more layers to the interior of a structure. Most coating systems provide for both mechanical and chemical adhesion. The system can be used to coat the entire or a portion of the culvert. Coating systems can be applied by machine or by hand.

For NonWorker-entry culverts, the installation process of cement mortar lining follows this process:

i. The culvert is cleaned to remove encrustations.

ii. Remote inspection of the culvert is carried out to ensure no infiltration and a relatively clean surface for adhesion of the coating.

iii. The cement is mixed on-site and pumped through lines to a spinner head.

iv. The spinner head is winched through the main at a required speed.

v. The cement is allowed to set.

vi. A uniform 0.15 in. coating of cement ins achieved.

vii. Ordinary Portland cement or a blend containing blast furnace slag is used for lining.

For worker entry culverts, spraying of gunite (dry concrete) or shotcrete (wet concrete) is possible. The sprayed concrete forms a new inner skin which enhances strength, reduces leakage, and prevents further loss of mortar. The concrete is trowelled after application to produce a smooth surface. Reinforcement may be fixed to the existing pipe wall prior to applying the concrete, adding to the structural strength and creating a new reinforced concrete culvert. The design of the concrete mix is important, to ensure full penetration and encapsulation of the reinforcement. Precast concrete units are commonly used to line the invert, especially if the flow in the pipe cannot be stopped off completely.

For NonWorker-entry culverts, the installation process of polymer lining follows this process:

i. The pipeline is cleaned to remove encrustation.

ii. Inspection of the culvert is carried out to ensure no infiltration and a relatively clean surface for adhesion of the coating.

iii. A two-component resin is mixed and pumped through lines to a spinner head.

iv. The spinner head is winched through the culvert at the required speed.

v. The resin is cured for a specified time.

vi. A uniform, smooth coating, typically 40 mils thick is achieved.

For worker-entry culverts polymer lining is normally carried out using specialized spray equipment and a hand spray gun. Most polymer systems use plural component spray equipment customized to the characteristics of the particular polymer to ensure properly mixed and metered output. Such equipment can sometimes be dropped into larger structures to accommodate extended application needs.

#### 3.2.9.5 QA/QC

Visual inspection and project documentation should be carried out at a minimum by the project inspector. The inspector should entirely know the products used and their installation process. Any deficiencies in the finished coating should be marked and repaired according to the coating or lining manufacturer's recommendations. For non-worker entry culverts a Closed Circuit TV or CCTV equipment can be used to address this topic; nevertheless, the inspector should be careful that the CCTV equipment can be used after the curing process has finished.

For cementitious and epoxy coatings, thickness of the applied coating should be randomly checked prior to the setoff the coating. Cementitious products generally will use a depth gauge to measure the applied thickness.

Spark testing or holiday detection can be used to detect holidays or pinholes in a polymer coating and inadequately welded seams in sheet liners. After the protective coating has set hard to the touch or after welding has been completed the system can be inspected with high-voltage holiday detection equipment. Surfaces should first be dry, and induced holiday is then be made on to the coated concrete surface and serves to determine the minimum or maximum voltage to be used to test the coating for holidays at that particular area.

Bond strength of polymer coatings can be measured in accordance with ASTM D4541. Any areas detected to have inadequate bond strength should be evaluated by the project engineer. Further bond tests may be performed in that area to determine the extent of potentially deficient bonded area and repairs made in accordance with the manufacturer's recommendations. An understanding between the owner and installer should be made prior to testing taking place regarding inadequate adhesion. There are many variables that play a part in analyzing the results of an adhesion test. Adhesion testing is a destructive test and consideration should be made as to the extent of testing in a structure in which the objective is to provide a monolithic coating

# CHAPTER 4

# INSPECTION AND MAINTENANCE REQUIREMENTS FOR RENEWED CULVERTS

## 4.1 Renewed Culvert Inspection

As per every constructed project, the renewed culvert must be inspected periodically, every three years or as conditions of the specific culvert necessitate earlier intervals. The inspection should include structural, hydraulic, and the overall performance of the culvert. Please refer to an earlier research report entitled “Asset Management Approach for Drainage Structures and Culverts,” by MRUTC.

A renewed culvert, must be inspected in the same way as any unrenowned culvert, please refer to section 3.1 of the present report. All basic elements of inspection must be followed; however, a specific attention must be directed to the trenchless method used. For instance, if the culvert was renewed using sliplining, the condition of the grouting and the new culvert material must be checked as well as all the procedures as if the culvert were in a new unrenowned condition. For any type of any type of trenchless renewal method used on a culvert, a special follow up must be taken for the capacity of the renewed culvert.

## 4.2 Culvert Maintenance

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

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

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

**Emergency Maintenance:** Emergency maintenance is performed in case of an unforeseen event, which may cause disturbance in the performance of a culvert. Emergency maintenance can be eliminated if timely routine maintenance and preventive maintenance activities are performed.

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

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

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

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

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

## 4.3 Culvert Cleaning

Routine cleaning maintenance is imperative to prolong the service life of the culvert. Culverts that become clogged with sedimentation and debris or deteriorate from rust can result in drainage back up, sinkholes, and damage to paved surfaces or other structures dependent on the culvert. To remove obstructions such as solids, roots, grease, mineral deposits, scaling and collapsed pipe, culvert cleaning machinery must be used (ASCE, 2008).

Figure 4-1 Example of Obstruction in Culvert (ASCE, 2008).

Cleaning with chemicals or high pressure water jetting can effectively clear the line or can be used in combination with other methods. These methods are generally used in a reactive mode, rather than proactively maintaining the culvert. A drive unit such as a horizontal direction drill can be used to easily control the debris while then vacuumed, excavated, or shoveled. Controlled pullback and thrust speeds on the drill are used in combination with the different attachments. One kind of attachment is a Barrel Cutter Tool, which is designed to loosen and remove heavy material in the culvert. Other attachments used are push buckets or pull buckets, depending on which side of the culvert is accessible. When cleaning culverts, there must be a means of trapping collected and disposing debris. EPA and state regulations need to be considered when disposing solids and hazardous waste. To fine clean the culvert, a brush attachment can be used at the end of this rodding machine.

Figure 4-2 Push Bucket (ASCE, 2008)

Figure 4-3 Pull Bucket (ASCE, 2008)

Figure 4-4Brush (ASCE, 2008)

# CHAPTER 5
# SURVEY OF TECHNOLOGY PROVIDERS

## 5.1 Introduction

The final intention of this report is to provide a comprehensive study and decision making procedures for the selection of appropriate trenchless technology methods for renewal of culverts and drainage structures. By thinking in that objective a survey was planned, and then distributed among all the technology providers known. The survey was divided in three major groups:

Part1. Contact Information, required surveyed to identify itself by filling 11 spaces with the necessary information.

Part 2. Culvert Asset Management, required to answer (19) nineteen questions. Fill in the blank, Yes/No and number ranking were some of the methods used for gather the information in this part of the survey.

Part 3. Culvert Construction, Repair, Renovation, Replacement (Renewal) and Usage of Trenchless Technologies, required the surveyed to select the types of Trenchless methods used and identify some key characteristics and limitations when using those methods

The survey was developed by the research team and uploaded to a website. The surveyed companies had the possibility to submit their responses either electronically or by fax. For an in deep look at the questionnaire please see APPENDIX A. We would like to thank our responders for their invaluable contribution. This chapter has the intention to show the results of the survey in a dynamic and comprehensive manner.

## 5.2 Survey's Answer Representation and Analysis

**Q1: Does your company work on culverts?**

The survey had 23 responses, out of those 13 companies or 57 percent replied to be capable to work on culverts, this question must be interpreted as work on renewal purposes by trenchless methods. It should be noticed that these numbers represent the industry average in the US. Figure 5-1 better describes the results.

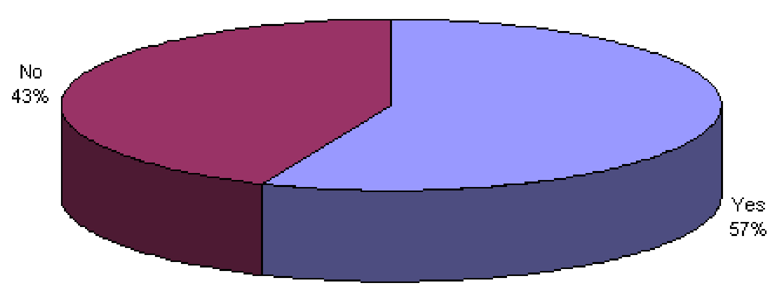


Figure 5-1 Q1: Does your company work on culverts?

**Q2: Does your company provide Culvert Inspection Services?**

A total of 8 companies or 35 percent of the 23 companies provide culvert inspection services, inspection services can include but are not limited to the following: Closed-Circuit television (CCTV), radar, laser, etc,.(see Figure 5-2).

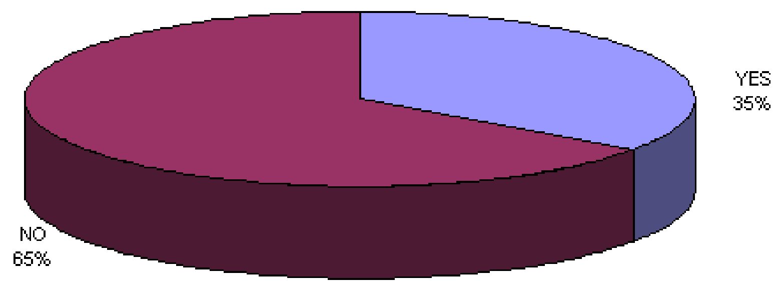


Figure 5-2 Q2: Does your company provide Culvert Inspection Services?

**Q3: Does you company have or use any Standard Inspection Services?**

From that 35 percent of companies being able to work on culverts, 3 of them or about 13 percent of them replied to use standards for the inspection of culverts. Some of the answers of those polled refer to ASTM, PCAP and NASSCO standards without specifying the exact standard number. This question corresponds to the third one in the questionnaire (see Figure 5-3).

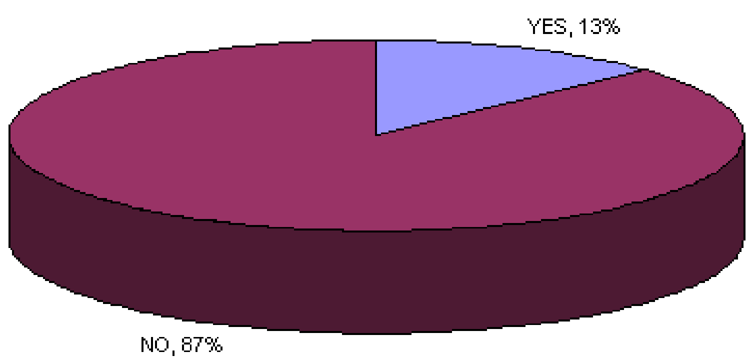


Figure 5-3 Q3: Does you company have or use any Standard Inspection Services?

**Q4: Rank the major problems responsible for failure of culverts.**

Question 4 solicited from those polled to rank the major problems affecting metal, concrete, and plastic culverts. From companies experiences, corrosion and abrasion ranked as the major problems affecting metal culverts; for concrete culverts, joint failure and cracking ranked as the major ones; and deflection and joint failure ranked as the major problems suffered by plastic culverts. From the listed problems for culverts, the survey returned that corrosion was almost not taken in account when the culvert is made with a plastic material (see Figure 5-4). It is also remarkable that wall thickness and hydraulic capacity remained as to the problems that less influence failures in any type of culvert material (metal, concrete and plastic) in an overall view. Other type of problem encountered the companies is sedimentation with a given rank of 3 out of 7. For illustration purposes number "7" was given to the factor that affects the most and number "0" to the factor that affects the least (see Figure 5-4).

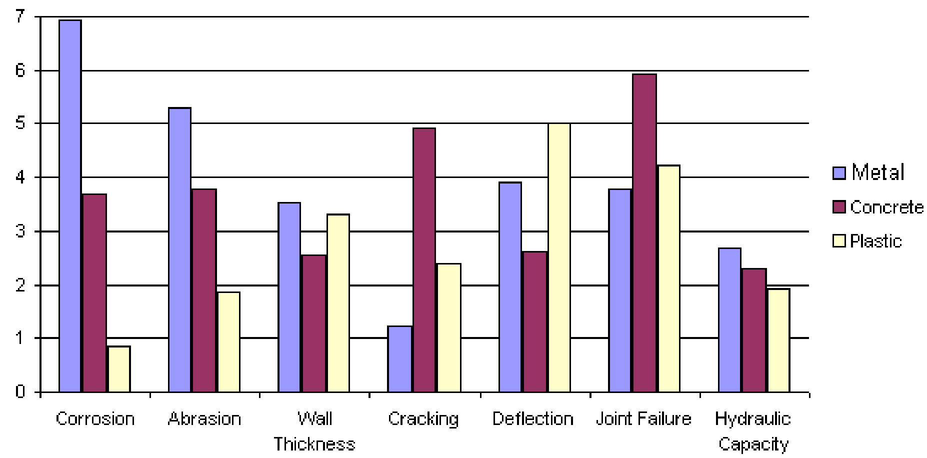


Figure 5-4 Q4: Rank the major problems responsible for failure of culverts.

**Q5: Circle the Culvert Materials which your company renews more.**

The industry and technology providers average response for question number 6, tell us that metal followed by concrete and plastic are the materials most renewed (see Figure 5-5). This tendency might be explained because of the great number of corrugated pipe culverts dug below the roads several decades ago, that nowadays are deteriorating due to their old age and the corrosion and abrasion effects over a long period of time. According to the survey, other types of renewed culvert materials are wood and clay pipes. For illustration purposes number "3" was given to the most used material and number "0" to the material least used.

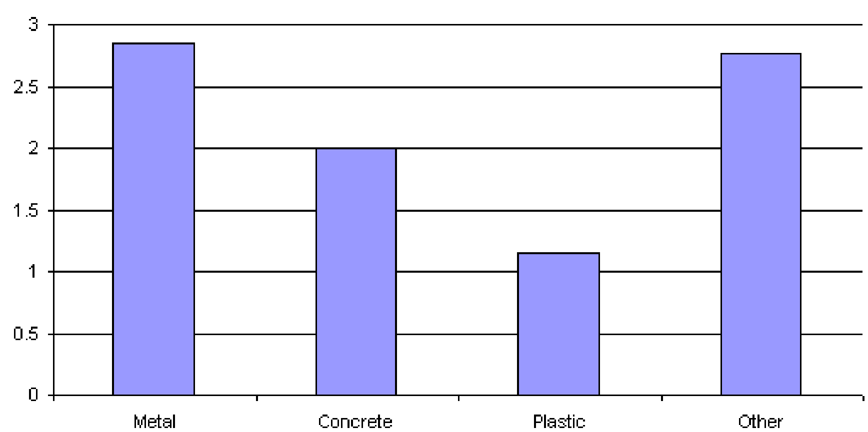


Figure 5-5 Q5: Circle the Culvert Materials which your company renews more.

**Q6: Which of Trenchless Renewal Method does your company carries out more?**

According to the findings of the survey, sliplining, pipe bursting and CIPP methods represent almost 45 percent of all the trenchless renewal methods used by companies. The use of the sliplining method (20 percent) is comparable to the summation of the use of grouting, panel lining, close-fit pipe and polymer coating. See Figure 5-6 for further details.

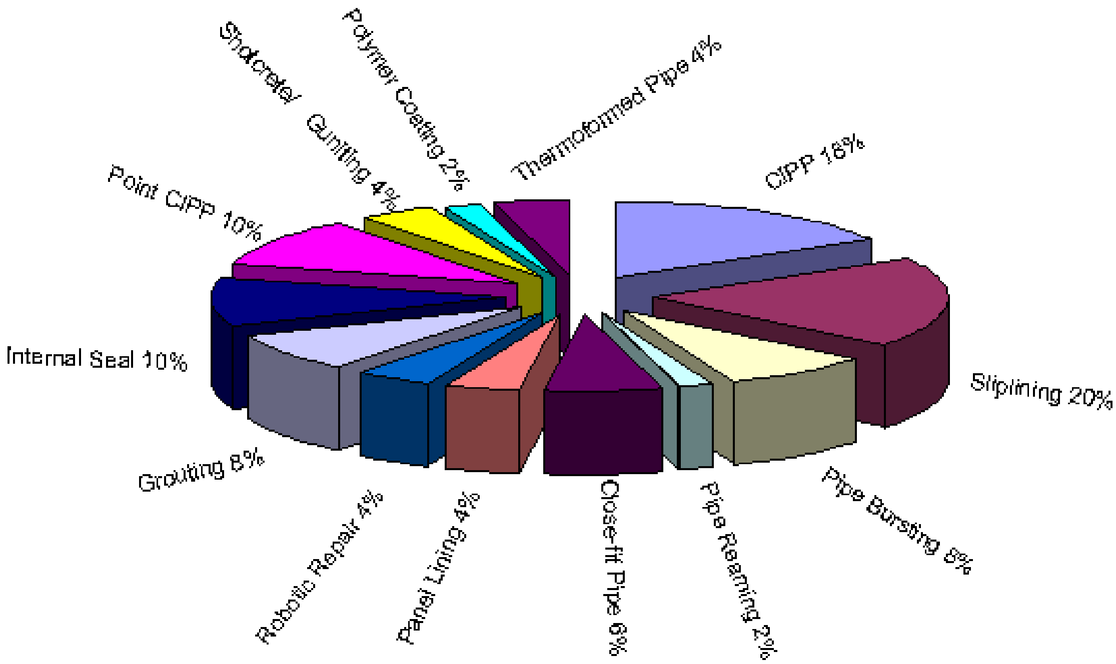


Figure 5-6 Q6: Which Trenchless Renewal Methods your company carries out?

**Q7: Rank the factors which govern the selection of a particular type of trenchless renewal method according to their importance.**

Cost of repair versus cost of replacement, as well as the condition of the existing culvert ranked as the two most influential factors when selecting a trenchless method for renewing a culvert. According to the survey findings aesthetics might not be a crucial issue. Figure 5-7 shows a number of factors that influences the selection of a trenchless renewal project. For illustration purposes number “13” was given to the factor that affects the most and number “0” to the factor that affects the least.

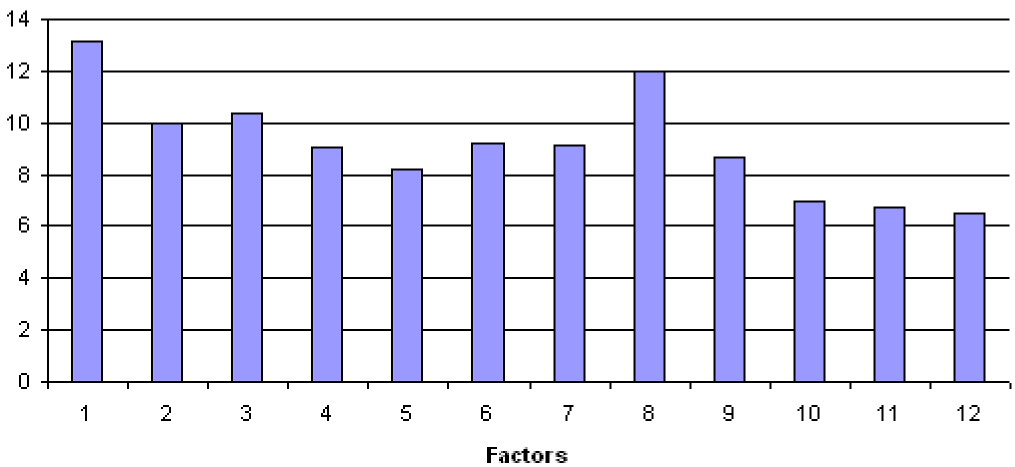


Figure 5-7 Q7: Rank the factors which govern the selection of a particular type of trenchless renewal method according to their importance.

List of Factors

1. Condition of the existing culvert and its suitability for renewal.
2. Capacity, alignment, and other characteristics of the culvert.
3. Site conditions.
4. Funding availability.
5. Availability and expertise of in-house forces.
6. User cost or time out of service.
7. Current and future needs of the area served by the culvert.
8. Cost of repair versus cost of replacement.
9. Effluent characteristics.
10. Availability and expertise of local contractors.
11. Availability and cost of materials and specialized equipment.
12. Aesthetics.

**Q8: Rank the critical pre-construction issues that play a wide role during planning phase on the following Trenchless Renewal Methods.**

The results encountered when the polled companies were asked about pre-construction issues, quite explains further more the findings in question 7 (see Figure 5-7). Because they show that the existing conditions of a culvert play a big role when deciding to use a Trenchless Renewal Method in culverts (see Figure 5-8). This issue could be explained because of the entry worker safety issues related to those trenchless methods. It is also important to note that the diameter, shape and material of the culvert is a critical factor when renewing culverts via trenchless. On the other hand, the type of flow is the factor that less influences pre-construction phase among all the trenchless methods listed in Figure 5-8. For illustration purposes number “7” was given to the factor that affects the most and number “0” to the factor that affects the least (see Figure 5-8).

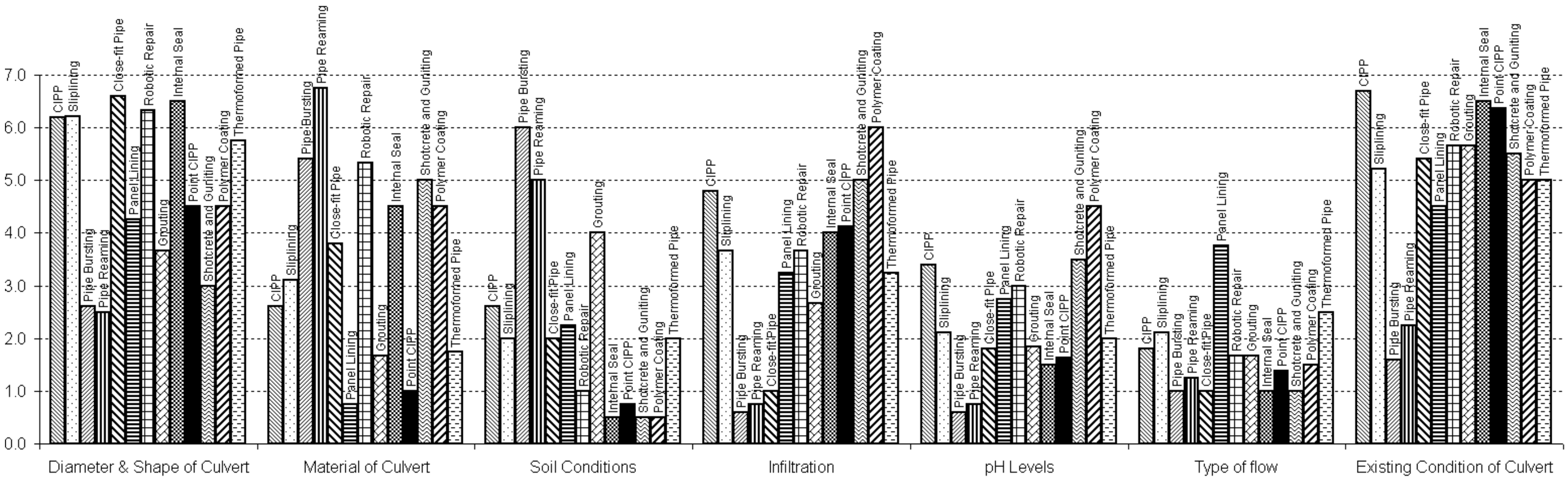


Figure 5-8 Q8: Rank the critical pre-construction issues that play a wide role during planning phase on the following Trenchless Renewal Methods.

**Q9: Rank the critical construction issues which are very important during installation of the following renewal methods.**

In the installation process of a trenchless renewal technique or "construction phase" the ranking of the issues encountered were more diverse. As expected, shotcrete/guniting, polymer coating and Internal seal methods that require worker entry ranked it as close to critical, moreover, the study also found that safety and flow diversion may become a greater issue in this stage. It is also remarkable that, in average ground stability is a not extremely critical construction issue for the Trenchless Renewal Methods listed below. For illustration purposes number "7" was given to the factor that affects the most and number "0" to the factor that affects the least (see Figure 5-9).

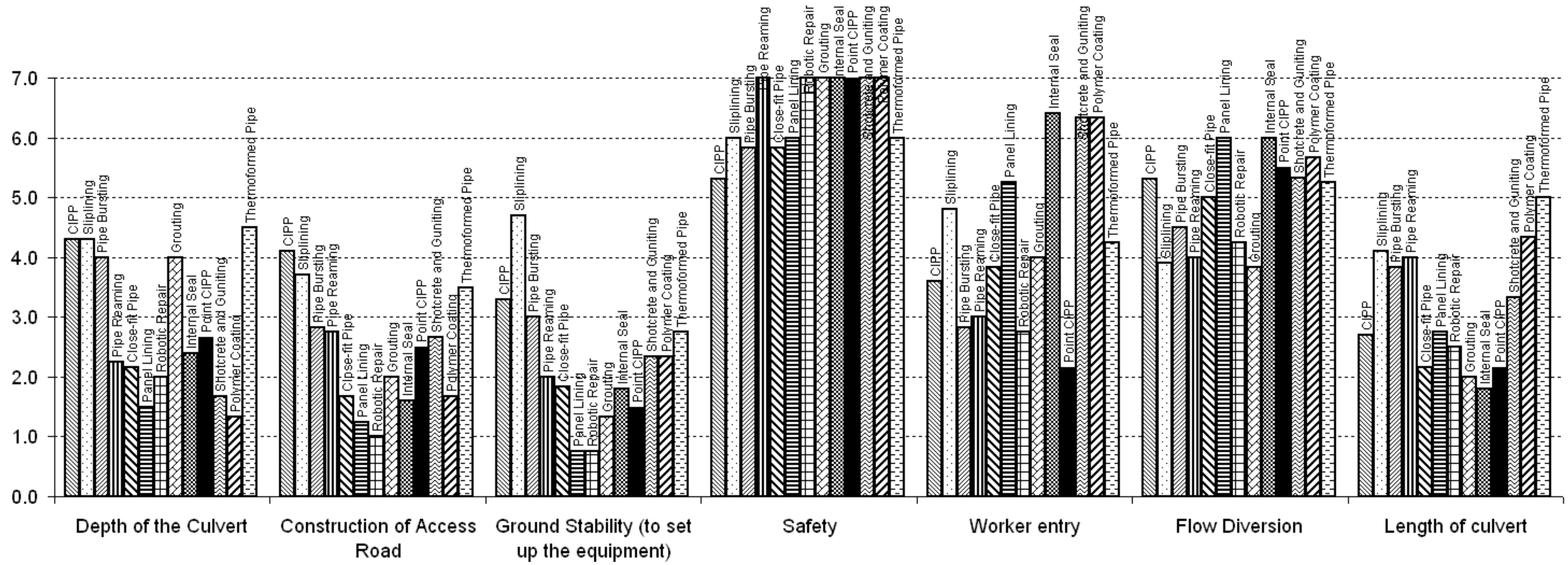


Figure 5-9 Q9: Rank the critical construction issues which are very important during installation of the following renewal methods.

**Q10: Rank the critical Post-Construction issues that are important following installation of the following renewal methods.**

In the post-construction phase, regular inspections and maintenance factors ranked as semi-critical factors followed by the length of service. For illustration purposes number "3" was given to the factor that affects the most and number "0" to the factor that affects the least (see Figure 5-10).

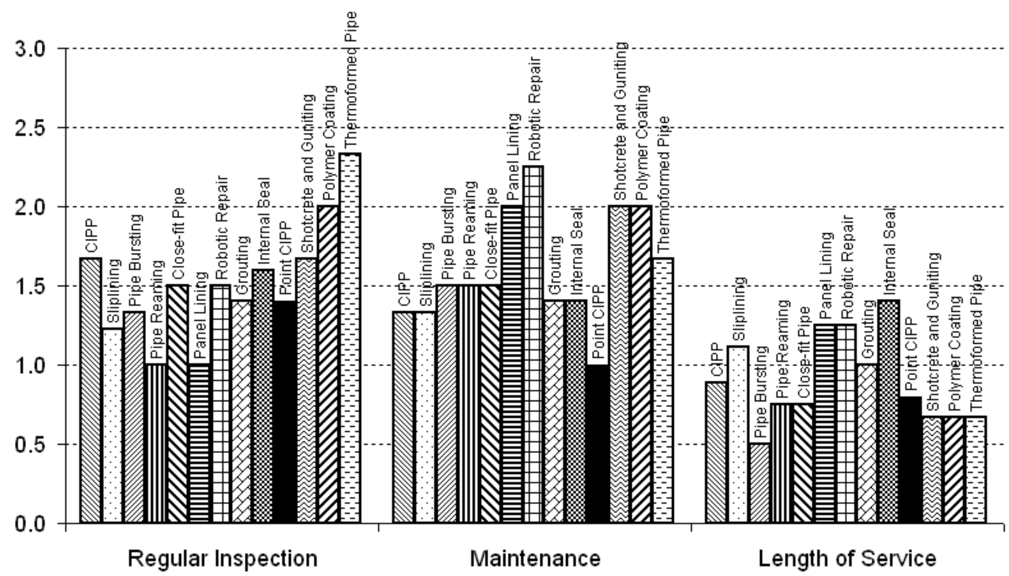


Figure 5-10 Q10: Rank the critical Post-Construction issues that are important following installation of the following renewal methods.

**Q11: What are the important factors in order to decide on whether to do an open-cut (traditional) replacement or to use trenchless renewal methods? (yes/no)**

When asked about if: depth of cover, location and traffic volume; are factors critical to decide whether to do an open-cut or trenchless renewal process, all the surveyed companies responded "yes" to all of them; showing that these factors deserve an important care when taking the decision of using a trenchless renewal process. However 8% of the companies believe that detour availability might not represent an important factor when deciding to use trenchless renewal methods.

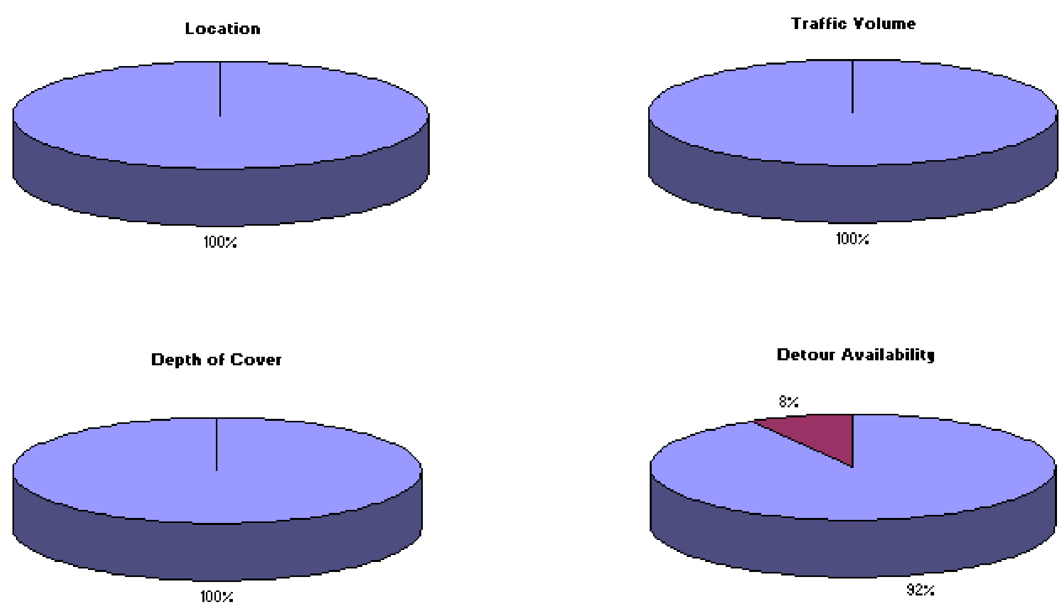


Figure 5-11 Q11: What are the important factors in order to decide on whether to do an open-cut (traditional) replacement or to use trenchless renewal methods? (yes/no)

**Q12: Provide the minimum and maximum culverts sizes your company has employed for the following Trenchless Renewal Methods in inches. Also specify the Maximum size of the culvert that you think can be installed by the following methods.**

The outcome values for this question vary widely; however, the lowest minimum value, the highest maximum size and the highest accepted size among all the surveyed is given below:

Table 5-1 Lowest and Highest values from replies to question 12.

| Method | Minimum Size in Inches | Maximum Size in Inches | Maximum Accepted Size in Inches |
|---|---|---|---|
| Cured-in-Place Pipe (CIPP) | 4 in. | 120 in. | 120 in. |
| Sliplining | 4 in. | 96 in. | 63 in. |
| Pipe Bursting | 3 in. | 36 in. | 30 in. |
| Pipe Reaming | 6 in. | 30 in. | 48 in. |
| Close-fit pipe | 8 in. | 24 in. | 48 in. |
| Panel Lining | 10 in. | Unlimited | Unlimited |
| Robotic Repair | 6 in. | 36 in. | 36 in. |
| Grouting | 6 in. | 120 in. | 120 in. |
| Internal Seal | 24 in. | 66 in. | 144 in. |
| Point CIPP | 6 in. | 48 in. | 120 in. |
| Shotcrete/Guniting | 48 in. | 77 in. | 144 in. |
| Polymer Coating | 48 in. | 96 in. | 144 in. |
| Thermoformed Pipe | 10 in. | 30 in. | 30 in. |

**Q13: What are the limitations for the following Trenchless Renewal Methods?**

When the survey turned its focus to the limitations of the trenchless renewal methods, some important findings appear. All the companies believe that bypassing is needed when using panel lining, shotcrete/guiniting, polymer coating and thermoformed pipe. It is remarkable as expected, that the bypassing represent an important problem among all the other methods listed in Figure 5-12. For the sliplining method it is unavoidable to observe (see Figure 5-12) that the "seals liner ends" problem is treated as a great limitation of that trenchless method. Here can be also noticed the importance of the need for worker entry for the shotcrete/guniting and for the polymer coating methods.

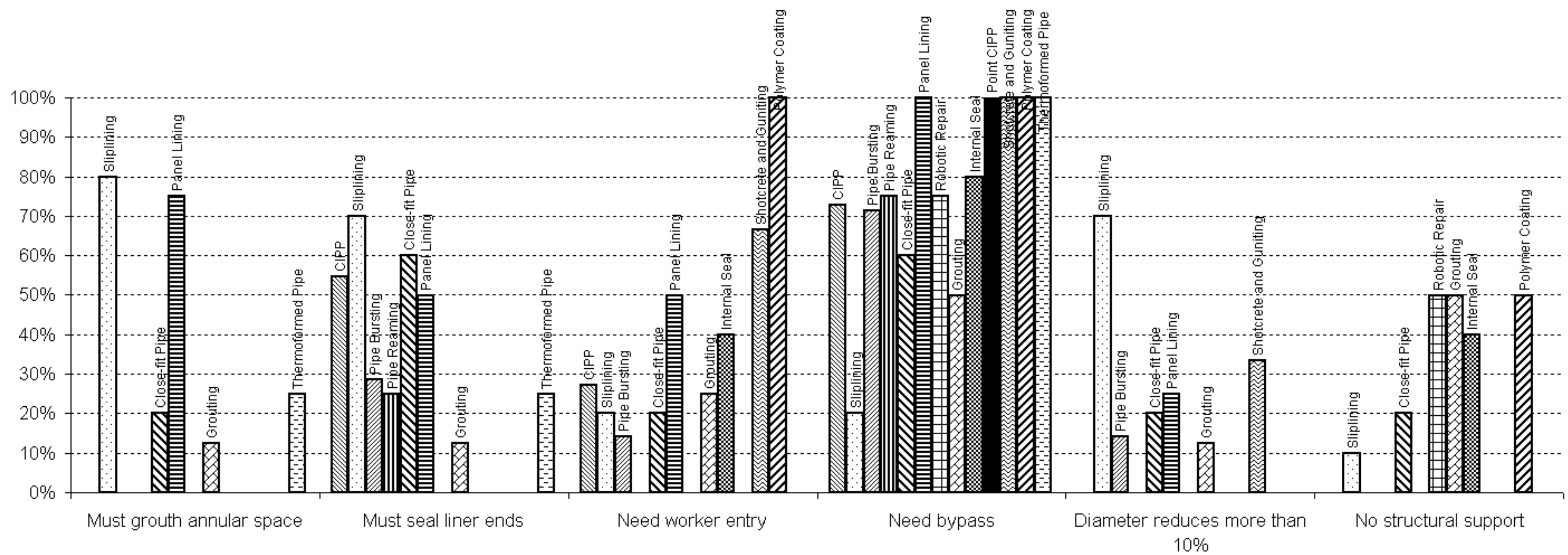

Figure 5-12 Q13: What are the limitations for the following Trenchless Renewal Methods?

**Q14: How many years of additional life can be provided to a deteriorated culvert after it is being renewed by the following methods?**

Any renewal method explained in this report has the intention to extend the operational life of a culvert. The survey found that by using trenchless renewal methods the additional amount of years can be provided to the life of this type of asset that is being discussed in this report. Almost 60 years can be added to a culvert when pipe bursting is used to renew it. Point CIPP, polymer coating, shotcrete and guniting, robotic repair, sliplining, close-fit pipe and pipe reaming also provide an additional life to a culvert with an average of 50 years, it should be noticed that point CIPP offers a local design improvement on the line thus it will not improve the total length of the culvert. Grouting not necessarily increases the operational life of a culvert as shown in Figure 5-13. It is also important to express, that additional operational life like the ones found can be only achieved by the use of good construction means and methods and a well controlled QA/QC program.

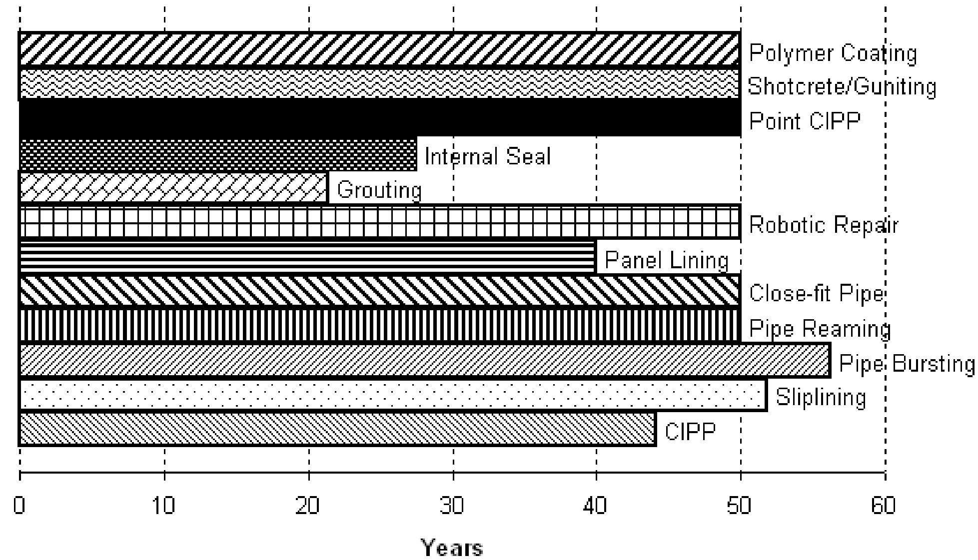


Figure 5-13 Q14: How many years of additional life can be provided to a deteriorated culvert after it is being renewed by the following methods?

Test on the trenchless renewal methods are frequently used by companies as a quality control measure. When they were asked about this test in question 15 some of them reported that they do not carry out test of any type, however the reader must take in account that the test might be carried out by other subcontracted companies. Another surveyed companies, replied this question explaining their use of several techniques, such as: physical properties, hydraulic tests and Closed Circuit Television (CCTV) for the Cured-in-Place Pipe, hydraulic tests and CCTV for sliplining as well for pipe bursting; air tests and CCTV for grouting and CCTV for point CIPP.

**Q16: Which of the trenchless renewal methods are suitable for the following problems executed in the culvert?**

One of the main focuses of this report is to suggest a method to renew culvert and storm sewers given a set of problems, question 16 inquires the surveyed companies to suggest a Trenchless Renewal Method to use in a given summarized list of problems. In average, companies believe that pipe bursting and robotic repair are suitable methods to renew culverts with all the defects shown in the list below. The survey also found that in a culvert affected by seam defects and scalling the use of internal seal to repair it is highly suitable. A highlighted finding in this question is the not suitability of CIPP and sliplining techniques for renewing culverts affected by misalignment / joint separation problems. For an insight review of the variety of problems encountered in culverts please refer to CHAPTER 2. For illustration purposes, number 3 was given to the most suitable method and number 0 to the least suitable method.

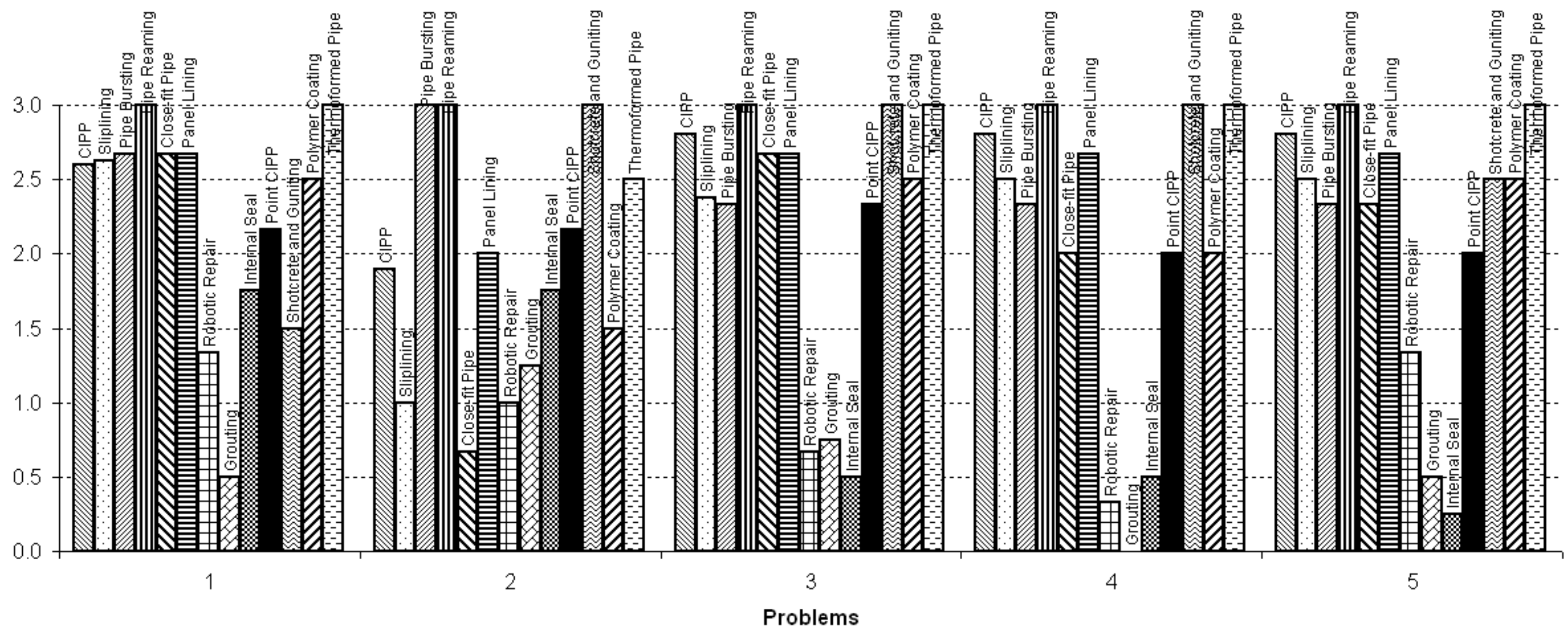


Figure 5-14 Q16: Which of the trenchless renewal methods are suitable for the following problems executed in the culvert?

List of the problems:

1. Corrosion & abrasion
2. Misalignment & joint separation
3. Seam defects & scalling
4. Delamination & efflorescence
5. Spalling & honey combing

**Q17: Is there any relation between the existing culvert material and the trenchless renewal method?**

Question 17 mainly focused on the suitability of the trenchless renewal methods for a given existing culvert material. The findings of the survey encountered that most of the renewal methods are suitable for concrete pipes; it is also remarkable that the grouting technique is more suitable for concrete culverts than other type of materials. The analysis of the survey also found that close fit pipe is highly suitable for concrete pipes and plastic pipes; the corrugated formations inside the steel pipe and the aluminum pipe tend to discourage the use of close-fit pipe in renewal of culverts. For illustration purposes, number 3 was given to the most suitable method and number 0 to the least suitable method. Please refer to Figure 5-15 for further investigation.

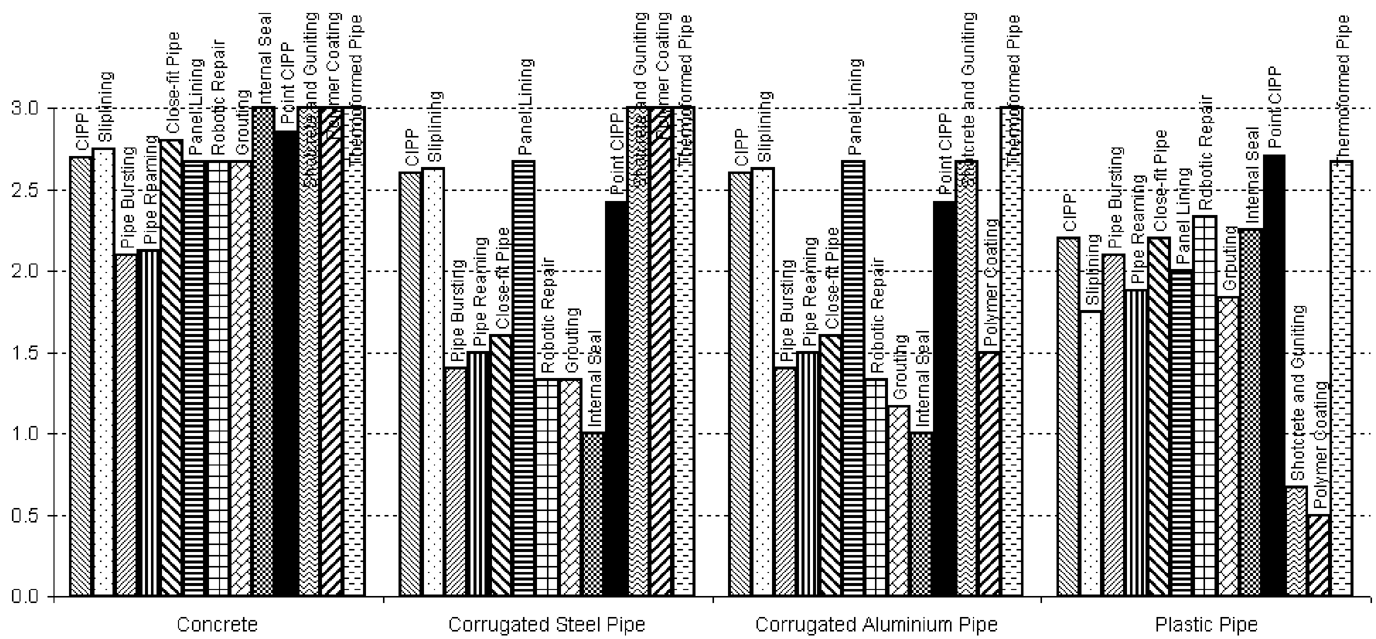


Figure 5-15 Q17: Is there any relation between the existing culvert material and the trenchless renewal method?

**Q18: What specification and Material does your company use for Trenchless Renewal Methods specifically for culvert applications?**

This open answer question had a wide variety of responses; however, a general summary will be provided in the next lines.

Specifications:

- The study found that the industry standard "ASTM F1216" is used by companies to renew culverts when using point CIPP and CIPP techniques.
- Previous company projects and the standard "AASHTO M326" are the specifications used by companies to renew culverts when using Sliplining techniques.
- Previous company projects are commonly used as guideline specifications when renewing culverts using pipe bursting.
- NASSCO standards are used in the Grouting renewal method.

Materials:

- For sliplining and pipe bursting, HDPE is widely used.
- PVC pipes are also used in sliplining renewal projects.
- When companies use CIPP or point CIPP techniques, they tend to use polyester (PE) materials and combination of resin/felt as well.
- In the grouting renewal method, concrete is the material of choice.

**Q19: Please use this space additional information to be considered in our study. Also please explain if your company uses any other type of Trenchless Technology.**

From all the responses there was not a research-worthwhile response to this question.

# CHAPTER 6
# CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Conclusions

A comprehensive study and decision-making procedures were provided in the previous chapters with the intention of giving the reader a specific approach when selecting the appropriate trenchless technology method for culvert renewal purposes. Maintenance and inspection also became a major item for this research, it is important for the reader and the industry to focus on maintenance and inspection procedures, because there is no point in renewing a culvert and not taking care of that renewed asset.

By reviewing the existing literature, the authors described various geo-environmental and mechanical factors affecting the deterioration of culverts. CHAPTER 2 presents the most appropriate trenchless renewal method for renew culverts and drainage systems. In addition, a survey of technology providers in CHAPTER 5 provides more information on different technologies. This chapter presents applications of different methods in culvert renewal.

As part of the objectives of the present research, the survey connects the findings and research of the academic part of the present study with the actual practices of the trenchless construction industry. The analysis of the survey provides detail answers to the most common problems or factors encountered in a trenchless renewal project of a culvert or drainage structure. The analysis of the data also explains which factors affect the most in the three divisions of a construction project (pre-construction, construction and post-construction). The authors also found from the survey that most of the trenchless renewal methods provide between 50 to 60 years of design life.

The investigators completed the following tasks for this project:

a) Reviewed existing literature for best practices on drainage infrastructure and culvert asset management.

b) Reviewed factors affecting culvert deteriorations and the selection of appropriate trenchless technology methods.

c) Reviewed and survey existing trenchless technology methods with potential use for construction, renewal, renovation and inspection of culverts and drainage infrastructures, and identify capabilities and limitations of each of these methods.

d) Identified inspection, asset management, and maintenance requirements of culverts and drainage infrastructures using trenchless technology methods.

e) Determined modification requirements in existing trenchless technologies to be used in culverts and drainage structures.

f) Collaborated with MDOT and ODOT to establish a database and decision support system for selection of appropriate trenchless technology methods.

g) Developed course modules for culvert asset management using trenchless technologies, comprehensive engineering and management procedures. Offer two workshops for MDOT and ODOT personnel. This task also includes technology transfer through paper publications and presentations at TRB, nationally and regional conferences.

## 6.2 Recommendations

It is recommended to develop standalone specifications for design, construction, and quality control for culvert renewal projects. The current AASHTO LRFD design and construction specifications should be referenced for loads, design factors, and limit states. The emphasis of these specifications will be on culvert rehabilitation methods that will focus in minimizing disruption to traffic and the road surface. For consistency and coordination with the AASHTO LRFD specifications, references to loads, factors and limit states should be made to the sections in the specifications and not to values directly whenever possible. Design examples should be provided as an appendix allowing for regular updates in line with changes to the main specifications minimizing revisions to the main body of the handbook as much as possible. The scope of the new proposed specifications should include: 1) designer experience with the implementation of the available culvert evaluation techniques, 2) industry trends in the design and construction of culverts, 3) changes made elsewhere in the LRFD Specifications that impact culvert design and analysis and 4) A comprehensive list of renewal systems, construction procedures, construction inspection, and quality assurance/quality control methods.

# CHAPTER 7
# GLOSSARY

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

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

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

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

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

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

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

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

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

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

**Allowable Headwater** Difference in elevation between the flowline of the culvert and the lowest point in which the water surface at upstream would either flood the highway or jeopardize the property.

**Alluvial** Referring to deposits of silts, sands, gravels, or similar detritus material that has been transported by running water.

**Anode** A metallic surface on which oxidation occurs, giving up electrons with metal ion going into solution or forming an insoluble compound of the metal.

**Amphibian** Any of the various cold-blooded, smooth-skinned vertebrate (with backbone) organisms such as toads, frogs, and salamanders, characteristically hatching as an aquatic larvae that breathe by means of gills and metamorphosing to an adult form having air-breathing lungs.

**Angle of Flare** Angle between direction of wingwall and the centerline of a culvert barrel.

**Angle of repose** The maximum angle, as measured from the horizontal, at which granular particles can stand.

**Angularity** The acute angle between the plane of the highway centerline along the bridge, and a line normal to the thread of the stream, i.e., the acute angle between the thread of the stream and a line normal to the centerline along bridge.

**Antidune** A particular type of bed form caused by water flowing over a mobile material such as sand.

**Apex** The highest point, the vertex.

**Approach Channel** The reach of channel upstream from a dam, bridge constriction, culvert, or other drainage structure.

**Apron** Protective material laid on a streambed to prevent scour commonly caused by some drainage facility or a floor lining of such things as concrete, timber, and riprap, to protect a surface from erosion.

**Aqueduct** An open or closed channel used to convey water, or an open conduit of things such as wood, concrete, or metal on a prepared grade, trestle, or bridge.

**Area Rainfall** Average rainfall of the area.

**Arid** Geographic areas that are dry, lacking moisture. Compare with desert and semi-arid.

**Armoring** A natural process whereby an erosion-resistant layer of relatively large particles is formed on a channel bank and/or channel bed due to the removal of finer particles by stream flow, i.e., the concentration of a layer of stones on the bed of the stream that are of a size larger than the transport capability of the recently experienced flow—the winnowing out of smaller material capable of being transported while leaving the larger sizes as armor that, for discharges up to that point in time, cannot be transported.

**Augmented Flow** The increased volume of water entering a channel, or allowed to run overland as waste waters from the diversion of surface flow or as water from another stream or watershed; or from waters withdrawn or collected upstream and released after use.

**Autogeneous Healing** A process where small cracks are healed by exposure to moisture, forming calcium carbonate crystals that accumulate along the crack edges, inter twining and building until the crack is filled.

**Backfill** The material used to refill the trench or the embankment placed over the top of the bedding and culvert.

**Backwater** The water upstream from an obstruction in which the free surface is elevated above the normal water surface profile.

**Baffle** A structure constructed on the bed of a stream or drainage facility to deflect or disturb the flow. Vanes or guides, a grid, grating, or similar device placed in a conduit to check eddy currents below them, and effect a more uniform distribution of velocities. Also a device used in a culvert or similar structure to facilitate fish passage.

**Bank** The side slopes or margins of a channel between which the stream or river is normally confined. More formally, the lateral boundaries of a channel or stream, as indicated by a scarp, or on the inside of bends, by the stream ward edge of permanent vegetal growth.

**Bar** It is an elongated deposit of alluvium, not permanently vegetated, within or along the side of a channel.

**Barrage** See Check Dam.

**Barrel Width** Commonly the inside, horizontal extent of a drainage facility.

**Base** The layers of specified material placed on the sub base or sub grade to support the pavement, surface course, or a drainage facility.

**Base Flow** In the U.S. Geological Survey's annual reports on surface-water supply, the discharge above which peak discharge data are published. The base discharge at each station is selected so that an average of approximately three peaks a year will be presented.

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

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

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

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

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

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

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

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

**Bed Slope** The longitudinal inclination of a channel bottom

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

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

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

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

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

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

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

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

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

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

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

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

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

**Buckling** Failure by an inelastic change in alignment.

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

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

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

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

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

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

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

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

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

**CFS** Rate of flow in cubic feet per second.

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

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

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

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

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

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

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

**Class** — The grade or quality of pipe.

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

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

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

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

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

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

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

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

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

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

**Drainage Area** The catchment area for rainfall and other forms of precipitation that is delineated as the drainage area producing runoff, i.e., contributing drainage area. Usually it is assumed that base flow in a stream also comes from the same drainage area.

**Drainage Basin** A part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water

**Drop Inlet** Type of inlet structure that conveys water from higher elevation to a lower outlet elevation smoothly without a free fall at the discharge.

**Durability** The ability to withstand corrosion and abrasion over time or service life.

**Embankment** A bank of earth, rock or material constructed above the natural ground surface over a culvert.

**End Section** A concrete or steel appurtenance attached to the end of a culvert for the purpose of hydraulic efficiency and anchorage.

**Energy Dissipator** Device to decrease hydraulic energy placed in ditches or culvert outfalls to reduce streambed scour.

**Energy Gradient** The increase or decrease in total energy of flow with respect to distance along the channel.

**Energy Grade Line** The line which represents the total energy gradient along the channel. It is established by adding together the potential energy expressed as the water surface elevation referenced to a datum and the kinetic energy at points along the stream bed or channel floor.

**Environmental Effects** Pertaining to the effects of highway engineering works on their surroundings and on nature.

**EPA** Environmental Protection Agency.

**Erosion (Culvert)** Wearing o grinding away of culvert material by water laden with sand, gravel or stones; generally referred to as abrasion.

**Erosion (Stream)** The process of the wearing of the streambed by flowing water.

**Exfiltration** The process by which storm water leaks or flows to the surrounding soil through such things as openings in a conduit, channel banks, or lake shores.

**FHWA** Federal Highway Administration.

**Filtration** The process of passing water through a filtering medium consisting of either granular material or filter geo textiles for the removal of suspended or colloidal matter.

**Fish Passage** Ability of fish to pass through bridge and culvert structure.

**Flexible Pipe** A pipe with relatively little resistance to bending i.e. as the load increases the vertical diameter decreases and the horizontal diameter increases, which is resisted by the soil around the pipe.

**Flood** In common usage, an event that overflows the normal flow banks or runoff that has escaped from a channel or other surface waters.

**Flood Frequency** The number of years, on the average, within which a given discharge will be equaled or exceeded.

**Flow** A stream of water; movement of such things as water, silt and/or sand; discharge; total quantity carried by a stream.

**Flow Line** A line formed by the invert of pipe.

**Flow Regime** The system or order characteristic of stream flow with respect to velocity, depth, and specific energy.

**Flow Steady** A flow in which the flow rate or quantity of fluid passing a given point per unit of time remains constant or a constant discharge with respect to time.

**Flow Subcritical** In this state, gravity forces are dominant so that the flow has a relatively low velocity and is often described as tranquil or streaming and the flow that has a Froude number less than unity.

**Flow Supercritical** In this state, inertia forces are dominant so that flow has a high velocity and is usually described as rapid or shooting and the flow that has a Froude number greater than unity.

**Flow Turbulent** The flow condition in which inertial forces predominate over viscous forces and in which head loss is not linearly related to velocity.

**Flow Uniform** Flow of constant cross section and average velocity through a reach of channel during an interval of time. It is also a constant flow of discharge, the mean velocity of which is also constant.

**Foundation** It is the material beneath the pipe.

**Freeboard** It is the vertical clearance between the lowest structural member of the bridge superstructure, the top culvert invert, or the point of escape in a canal or channel to the water surface elevation of a flood.

**Free Flow** A condition of flow through or over a structure not affected by submergence.

**Free Outlet** A free outlet has a tailwater equal to or lower than critical depth. For culverts having free outlets, lowering of the tailwater has no effect on the discharge or the backwater profile upstream of the tailwater.

**Froude Number** A dimensionless number (expressed as $F = V/(gy)1/2$) that represents the ratio of inertial to gravitational forces, i.e., at a Froude number of unity the flow velocity and wave celerity are equal

**Galvanizing** It is the process of applying of a thin layer of zinc to steel by hot dipping.

**Gauge** Thickness of sheet metal used in corrugated metal pipe.

**Grade** The longitudinal slope of the channel as a ratio of the drop in elevation to the distance.

**Gradient** See Grade.

**Gravel** The particles, usually of rock, whose diameter is between 2 mm and 100 mm (0.08 in. and 4.0 in.).

**Groundwater** Water contained in the subsoil, which is free to move either vertically or horizontally.

**Groundwater runoff** That part of the runoff that has passed into the ground, has become groundwater, and has been discharged into a stream channel as spring or seepage water.

**Grout** A fluid mixture of cement and water or of cement, sand, and water used to fill joints and voids.

**Hairline Cracks** Very small cracks that form in the surface of the concrete pipe due to tension caused by loading.

**Head** The height of water above any point, plane, or datum of reference. Used also in various computations, such as energy head, entrance head, friction head, static head, pressure head, lost head, etc.

**Headloss** The loss of energy reported in feet of head.

**Head Velocity** The distance a body must fall freely under the force of gravity to acquire the velocity it possesses; the kinetic energy, in meters [feet] of head, possessed by a given velocity.

**Headwall** A concrete structure placed at the inlet and outlet of a culvert to protect the embankment slopes, anchor the culvert and prevent undercutting.

**Headwater** It is the distance between the flowline elevation at the inlet of a culvert and the water surface at the inlet.

**Holidays** Defect in protective coating on metal surface.

**Hydraulics** The mechanics of fluids, mainly water.

**Hydraulic Gradeline** An imaginary line, representing the total energy and paralleling the free water surface if the flows were at atmospheric pressure.

**Hydraulic Friction** A force resisting flow that is exerted on contact surface between a stream and its containing channel.

**Hydraulic Jump** An abrupt rise in the water surface in the direction of flow when the type of flow changes from supercritical to subcritical.

**Hydraulic Radius** The cross-sectional area of flow divided by the length of that part of its periphery in contact with its containing conduit; the ratio of area to wetted perimeter.

**Hydrology** The science of water related to its properties and distribution in the atmosphere, on the land surface, and beneath the surface of the land.

**Improved Inlet** An improved inlet has an entrance geometry that decreases the flow constriction at the inlet and thus increases the capacity of the culverts.

**Impermeable Strata** It is a stratum in which texture is such that water cannot move perceptibly through it under pressures ordinarily found in subsurface water.

**Impervious** It is impermeable to the movement of water.

**Impingement** Suspended solid particles or gas bubbles in water striking the surface or turbulence along breaking down the protective layer of a metal or a concrete surface.

**Infiltration** The flow of a fluid into a substance through pores or small openings. It connotes flow into a substance in contradistinction to the word percolation, which connotes flow through a porous substance.

**Inflow** The rate of discharge arriving at a point (in a stream, structure, or reservoir).

**Inversion Lining** Process of inverting pliable tube into existing pipe with hydrostatic or air pressure to reline existing pipe. The tube is forced against the existing pipe and thermosetting resins to provide structural strength and improved smoothness.

**Invert** The invert is the flowline of a culvert (inside bottom) or the flow line in a channel cross section, pipe, or culvert or the lowest point in the channel cross section or at flow-control devices such as weirs or dams.

**Inundate** To cover or fill as with a flood.

**Joint** A connection between two pipe sections made either with or without the use of additional parts.

**Lateral** A conduit, ditch, canal, or channel conveying water diverted from a main conduit, canal, or channel for delivery to distributaries; sometimes considered a secondary ditch.

**Launching** Release of undercut material (stone riprap, rubble, slag, etc.) down slope; if sufficient material accumulates on the stream bank face, the slope can become effectively armored.

**Link Pipe Lining** Method of pulling a short, pipe line segment to the damaged point in an existing pipe and jacking the segment into place.

**Load- sediment load** The amount of sediment being moved by a stream.

**Long Span Culverts** These culverts are designed on structural aspects rather than hydraulic considerations. Usually constructed of structural plates, which exceed defined sizes for pipes, pipe arches, arches or special shape that involve a long radius or curvature in the crown or side plates.

**Manning's Equation** An equation for the empirical relationship used to calculate the barrel friction loss in culvert design.

**Meander** The winding of a stream channel. Any reverse or letter-S channel pattern fashioned in alluvial materials by erosion of the concave bank, which is free to shift its location and adjust its shape as part of a stage in the migratory movement of the channel as a whole down an erodible, alluvial valley.

**Metal Corrosion** It is an electrical process involving an electrolyte (moisture), an anode (the metallic surface where oxidation occurs), a cathode (the metallic surface that accepts electrons and does not corrode), and a conductor (the metal pipe itself).

**Minor Head Losses** Head lost through transitions such as entrances, outlets, obstructions, and bends.

**Moisture** Water diffused in the atmosphere or the ground.

**Normal Flow** Normal flow occurs in a channel reach when the discharge, velocity and depth of flow do not change throughout the reach. The water surface profile and channel bottom slope will be parallel. This type of flow will exist in a culvert operating on a steep slope provided the culvert is sufficiently long.

**Outfall** The discharge end of drains or sewers.

**Outlet Control** A condition where the relation between headwater elevation and discharge is controlled by the conduit, outlet, or downstream conditions of any structure through which water may flow.

**Parameter** A characteristic descriptor, such as a mean or standard deviation or sometimes considered as a variable comprised of the product of two or more variables.

**Peak Discharge** The highest value of the stage or discharge attained by a flood; thus, peak stage or peak discharge.

**Permeability** The property of a material that permits appreciable movement of water through it when it is saturated and movement is actuated by hydrostatic pressure of the magnitude normally encountered in natural subsurface water.

**Perforation** Complete penetration of metal culvert that generally occurs in the invert.

**pH Value** The log of the reciprocal of the hydrogen ion concentration of a solution. The pH value of 7.0 is neutral; values of less than 7.0 are acid; values of more than 7.0 are basic.

**Pipe** A tube or conduit.

**Pipe Diameter** The inside diameter of a pipe.

**Piping Action** A process of subsurface erosion in which surface runoff flows along the outside of a culvert and with sufficient hydraulic gradient erodes and carries away soil around or beneath the culvert.

**Polyethylene Pipe** Plastic pipe manufactured from polymerized ethylene in corrugated or smooth configurations of various dimensions.

**Polymer Coating** A protective coating of plastic polymer resins with other materials.

**Ponding** Water back up in a channel or ditch as the result of a culvert of inadequate capacity or design to permit the water to flow unrestricted.

**Reinforced Concrete Pipe** A concrete pipe designed with reinforcement as a composite structure.

**Rigid Pipe** A pipe with high resistance to bending.

**Riprap** Rough stones of various sizes placed compactly or irregularly to prevent scour by water or debris.

**Roughness Coefficient (n)** A factor in the Kutter, Manning, and other flow formulas representing the effect of channel roughness upon energy losses in flowing water.

**Resistivity (Soil)** An electrical measurement in ohm-cm, which is one of the factors for estimating the corrosiveness of a given soil to metal.

**Runoff** That part of precipitation carried off from the area upon which it falls.

**Sacrificial Coating** A coating over the base material to provide protection to the base material. Examples include galvanizing on steel and cladding on aluminum.

**Sacrificial Thickness** Additional pipe thickness provided for extra service life of the culvert in an aggressive environment.

**Scour (outlet)** The process of degradation of the channel at the culvert outlet as a result of erosive velocities.

**Seepage** It is the process of escaping of water through the soil, or water flowing from a fairly large area of the soil instead of from one spot, as in the case of a spring.

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

**Skew** The acute angle formed by the intersection of the line normal to the centerline of the road with the centerline of a culvert or other structure.

**Slabbing** The radial tension failure of concrete pipe resulting from the tendency of curved reinforcing steel or cage to straighten out under the load.

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

# CHAPTER 8
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# APPENDIX A

# SURVEY

# The University of Texas at Arlington

# Center for Underground Research and Education (CUIRE)

# Department of Civil Engineering

## Research Title:

## Use of Trenchless Technologies for a Comprehensive Asset Management of Culverts and Drainage Infrastructures

# SURVEY FORM

The University of Texas at Arlington and University of Cincinnati are collaborating on an important Midwest Regional University Transportation Center (MRUTC) project titled "Use of Trenchless Technologies for a Comprehensive Asset Management of Culverts and Drainage Infrastructures." The main objective of this project is to provide a comprehensive study and decision making procedures for the selection of appropriate trenchless technology methods for renewal, renovation, and maintenance (collectively called renewal) of culverts and drainage infrastructures.

This national survey will provide valuable information regarding the asset management of culverts and use of trenchless technologies for culvert renewal and maintenance. There are few questions in this survey and we estimate that it will take around 20-25 minutes to complete. There are no risks or individual benefits by associated with completing this survey.

We will acknowledge your help in completing this questionnaire in our final report, but we will not refer to your individual responses, therefore, your input will be anonymous. Once again, we greatly appreciate your help in advance and we will send you a copy of the final report scheduled for late summer 2008.

**Your assistance in completing this survey will be kept confidential.**

For more information Contact:
*Dr. Mohammad Najafi,*
*Director of CUIRE,*
*The University of Texas at Arlington*
*Tel: 817-272-0507*
*Email:* najafi@uta.edu

## A.1 Part 1 Contact Information

NAME OF THE COMPANY: ____ WEBSITE: ____

RESPONDENT'S NAME: ____ TITLE: ____

ADDRESS COMPANY): ____

CITY: ____ STATE: ____ ZIP CODE: ____

PHONE: ____ FAX: ____ E-MAIL: ____

## A.2 Part 2 Culvert Asset Management

Definition of Culvert:

A structure of less than 6.1-m (20-ft) span as measured along the road centerline which is used as an underground drainage system for highways is classified as a culvert.

Question 1: Does your company work on Culvert? ☐ YES ☐ NO

If yes, continue with the survey, if NO, Thank You for your time.

Question 2: Does your company provide Culvert Inspection Services? ☐ YES ☐ NO

Question 3: Does your company have or use any Standard Inspection Guidelines? ☐ YES ☐ NO

If yes, please provide what standard you use

Question 4: Rank the major problems responsible for failure of culverts. (Rank "1" for the factor which affects more and "8" to the problem which affects the least for the problems listed below).

| Factors* | Metal | Concrete | Plastic | Other (Specify) |
|---|---|---|---|---|
| Corrosion | | | | |
| Abrasion | | | | |
| Wall Thickness | | | | |
| Cracking | | | | |
| Deflection | | | | |
| Joint Failure | | | | |
| Hydraulic Capacity | | | | |
| Other *(Specify)* | | | | |

*The definitions of all the factors are hyperlinked and explained in the end of the form

**Question 5:** Rank the Culvert Materials which your company renews more in descending order. (Number "1" for culvert which is renewed most to Number "4" which your company has renewed least). If the material is not listed in the Drop down list then choose "other" and specify the material outside the table in the space given.

| Rank | Material |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |

**Other** *(Specify)*

### A.3 Part 3 Culvert Construction, Repair, Renovation, Replacement (Renewal) and Usage of Trenchless Technologies

**Question 6:** Check the boxes for the **Trenchless Renewal Methods** which your company carry out? How many installations do your company carry out do every year? What **safety measures** does your company carry out on these methods?

| Methods* | Installation/Year | Safety Measures |
|---|---|---|
| Cured In Place Pipe (CIPP) | | |
| Sliplining | | |
| Pipe Bursting | | |
| Pipe Reaming | | |
| Close Fit Pipe | | |
| Panel Lining | | |
| Robotic Repairs | | |
| Grouting | | |
| Internal Seals | | |
| Point CIPP | | |
| Shotcrete and Guniting | | |
| Polymer Coating | | |
| Thermoformed Pipe | | |
| Spiral Wound Pipe (Grouted) | | |
| Spiral Wound Pipe (Ungrouted) | | |
| **Other** *(Specify)* | | |

*The definitions of all the Trenchless Renewal Methods are hyperlinked and explained in the end of the form

**Question 7**: Rank the factors below which govern the selection of a particular type of Trenchless Renewal Methods according to their importance? (1 to be highest through 14 to be lowest)

- Condition of the existing culvert and its suitability for renewal
- Current and future needs of the area served by the culvert
- Capacity, alignment, and other characteristics of the culvert
- Cost of repair versus cost of replacement
- Site conditions
- Effluent characteristics
- Funding availability
- Availability and expertise of local contractors
- Availability and expertise of in-house forces
- Availability and cost of materials and specialized equipment
- User cost or time out of service
- Aesthetics
- Condition of the existing culvert and its suitability for renewal
- Other (Specify)

**Question 8:** Rank the critical **pre-construction issues** that play a wide role during planning phase of the following Trenchless Renewal Methods. (1 to be highest through 8 to be lowest)

| Methods | Diameter & Shape of Culvert | Material of Culvert | Soil Conditions | Infiltration | pH Levels | Type of Flow | Existing Condition of Culvert | Other (Specify) |
|---|---|---|---|---|---|---|---|---|
| Cured In Place Pipe (CIPP) | | | | | | | | |
| Sliplining | | | | | | | | |
| Pipe Bursting | | | | | | | | |
| Pipe Reaming | | | | | | | | |
| Close Fit Pipe | | | | | | | | |
| Panel Lining | | | | | | | | |
| Robotic Repairs | | | | | | | | |
| Grouting | | | | | | | | |
| Internal Seals | | | | | | | | |
| Point CIPP | | | | | | | | |
| Shotcrete and Guniting | | | | | | | | |
| Polymer Coating | | | | | | | | |
| Thermoformed Pipe | | | | | | | | |
| Spiral Wound Pipe (Grouted) | | | | | | | | |
| Spiral Wound Pipe (Ungrouted) | | | | | | | | |
| **Other** *(Specify)* | | | | | | | | |

*The definitions of all the Trenchless Renewal Methods are hyperlinked and explained in the end of the form

**Question 9:** Rank the **critical construction issues** which are very important during installation of the following renewal methods? (1 to be highest through 8 to be lowest)

| Methods | Depth of Culvert | Construction of Access Road | Ground Stability (to Set up Equipments) | Safety | Worker entry | Flow Diversion | Length of Culvert | Other (Specify) |
|---|---|---|---|---|---|---|---|---|
| Cured In Place Pipe (CIPP) | | | | | | | | |
| Sliplining | | | | | | | | |
| Pipe Bursting | | | | | | | | |
| Pipe Reaming | | | | | | | | |
| Close Fit Pipe | | | | | | | | |
| Panel Lining | | | | | | | | |
| Robotic Repairs | | | | | | | | |
| Grouting | | | | | | | | |
| Internal Seals | | | | | | | | |
| Point CIPP | | | | | | | | |
| Shotcrete and Guniting | | | | | | | | |
| Polymer Coating | | | | | | | | |
| Thermoformed Pipe | | | | | | | | |
| Spiral Wound Pipe (Grouted) | | | | | | | | |
| Spiral Wound Pipe (Ungrouted) | | | | | | | | |
| **Other** *(Specify)* | | | | | | | | |

*The definitions of all the Trenchless Renewal Methods are hyperlinked and explained in the end of the form

**Question 10:** Rank the critical **Post-construction issues** that are important following installation of the following renewal methods? (1 to be highest through 4 to be lowest)

| Methods | Regular Inspection | Maintenance | Length of Service | Other (Specify) |
|---|---|---|---|---|
| Cured In Place Pipe (CIPP) | | | | |
| Sliplining | | | | |
| Pipe Bursting | | | | |
| Pipe Reaming | | | | |
| Close Fit Pipe | | | | |
| Panel Lining | | | | |
| Robotic Repairs | | | | |
| Grouting | | | | |
| Internal Seals | | | | |
| Point CIPP | | | | |
| Shotcrete and Guniting | | | | |
| Polymer Coating | | | | |
| Thermoformed Pipe | | | | |
| Spiral Wound Pipe (Grouted) | | | | |
| Spiral Wound Pipe (Ungrouted) | | | | |
| **Other** *(Specify)* | | | | |

*The definitions of all the Trenchless Renewal Methods are hyperlinked and explained in the end of the form

**Question 11:** Provide the minimum and maximum culverts sizes your company has employed for the following Trenchless Renewal Methods in inches. Also specify the Maximum size of the culvert that you think can be installed by the following methods.

| Methods | Maximum Size in Inches | Minimum Size in Inches | Maximum Accepted Size in Inches |
|---|---|---|---|
| Cured In Place Pipe (CIPP) | | | |
| Sliplining | | | |
| Pipe Bursting | | | |
| Pipe Reaming | | | |
| Close Fit Pipe | | | |
| Panel Lining | | | |
| Robotic Repairs | | | |
| Grouting | | | |
| Internal Seals | | | |
| Point CIPP | | | |
| Shotcrete and Guniting | | | |
| Polymer Coating | | | |
| Thermoformed Pipe | | | |
| Spiral Wound Pipe (Grouted) | | | |
| Spiral Wound Pipe (Ungrouted) | | | |
| **Other** *(Specify)* | | | |

*The definitions of all the Trenchless Renewal Methods are hyperlinked and explained in the end of the form

**Question 12:** What are the **limitations** for the following **Trenchless Renewal Methods**? If your company has encountered some more limitations during installing these methods please specify it in the space given below

| Methods | Must Grout annular Space | Must Seal Liner Ends | Need Worker Entry | Need Bypass | Diameter Reduces More than 10% | No Structural Support | Other (Specify) |
|---|---|---|---|---|---|---|---|
| Cured In Place Pipe (CIPP) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Sliplining | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Pipe Bursting | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Pipe Reaming | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Close Fit Pipe | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Panel Lining | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Robotic Repairs | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Grouting | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Internal Seals | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Point CIPP | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Shotcrete and Guniting | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Polymer Coating | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Thermoformed Pipe | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Spiral Wound Pipe (Grouted) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Spiral Wound Pipe (Ungrouted) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| **Other** *(Specify)* | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

*The definitions of all the Trenchless Renewal Methods are hyperlinked and explained in the end of the form

**Question 13**: What are the important factors in order to decide on whether to do an open-cut (traditional) replacement or to use trenchless renewal methods?

| Factors | Consideration | |
|---|---|---|
| | Yes | No |
| Location | ☐ | ☐ |
| Traffic Volume | ☐ | ☐ |
| Detour Availability | ☐ | ☐ |
| Depth of Cover | ☐ | ☐ |
| Other *(Specify)* | ☐ | ☐ |

**Question 14:** According to your company how many years of **additional life** can be provided to a deteriorated culvert after it is being renewed by the following methods? Also provide approximate cost of installation per linear ft/in. of diameter.

| Methods | Additional Life in Years | Average Cost/Linear ft/inches of Diameter |
|---|---|---|
| Cured In Place Pipe (CIPP) | | |
| Sliplining | | |
| Pipe Bursting | | |
| Pipe Reaming | | |
| Close Fit Pipe | | |
| Panel Lining | | |
| Robotic Repairs | | |
| Grouting | | |
| Internal Seals | | |
| Point CIPP | | |
| Shotcrete and Guniting | | |
| Polymer Coating | | |
| Thermoformed Pipe | | |
| Spiral Wound Pipe (Grouted) | | |
| Spiral Wound Pipe (Ungrouted) | | |
| Other *(Specify)* | | |

*The definitions of all the Trenchless Renewal Methods are hyperlinked and explained in the end of the form

**Question 15:** Does your company typically perform any **test on the Renewal Methods** after they are being applied to the existing deteriorated culvert?

| Methods | Tests Carried Out |
| --- | --- |
| Cured In Place Pipe (CIPP) | |
| Sliplining | |
| Pipe Bursting | |
| Pipe Reaming | |
| Close Fit Pipe | |
| Panel Lining | |
| Robotic Repairs | |
| Grouting | |
| Internal Seals | |
| Point CIPP | |
| Shotcrete and Guniting | |
| Polymer Coating | |
| Thermoformed Pipe | |
| Spiral Wound Pipe (Grouted) | |
| Spiral Wound Pipe (Ungrouted) | |
| **Other** *(Specify)* | |

*The definitions of all the Trenchless Renewal Methods are hyperlinked and explained in the end of the form

**Question 16:** Which of the Trenchless Renewal Methods are suitable for the following problems executed in the culvert? Grade the suitability of these methods as

4 Not Suitable
3 Moderately Suitable (If there is no other option)
2 Suitable (If the deteriorating factor is not the primary cause of deterioration)
1 Highly Suitable

| Methods | Corrosion & Abrasion | Misalignment & Joint Separation | Seam Defects & Scalling | Delamination & Efflorescence | Spalling & Honey Combing | Other (Specify) |
|---|---|---|---|---|---|---|
| Cured In Place Pipe (CIPP) | | | | | | |
| Sliplining | | | | | | |
| Pipe Bursting | | | | | | |
| Pipe Reaming | | | | | | |
| Close Fit Pipe | | | | | | |
| Panel Lining | | | | | | |
| Robotic Repairs | | | | | | |
| Grouting | | | | | | |
| Internal Seals | | | | | | |
| Point CIPP | | | | | | |
| Shotcrete and Guniting | | | | | | |
| Polymer Coating | | | | | | |
| Thermoformed Pipe | | | | | | |
| Spiral Wound Pipe (Grouted) | | | | | | |
| Spiral Wound Pipe (Ungrouted) | | | | | | |
| **Other** *(Specify)* | | | | | | |

*The definitions of all the Trenchless Renewal Methods are hyperlinked and explained in the end of the form

**Question 17:** Is there any **relation between the existing culvert material and the New Trenchless Renewal Method** to be used? For e.g. suppose Cured In Place Pipe is best solution if the existing culvert is a concrete culvert. If yes specify the relation in terms of :

Not Suitable
Moderately Suitable (If there is no other option)
Suitable (If the Renewal Method is OK to be used for the particular culvert Material but not excellent)
Highly Suitable

| Methods | Concrete Culvert | Corrugated Steel Pipe Culvert | Corrugated Aluminium Culvert | Plastic Pipe Culvert | Other (Specify) |
|---|---|---|---|---|---|
| Cured In Place Pipe (CIPP) | | | | | |
| Sliplining | | | | | |
| Pipe Bursting | | | | | |
| Pipe Reaming | | | | | |
| Close Fit Pipe | | | | | |
| Panel Lining | | | | | |
| Robotic Repairs | | | | | |
| Grouting | | | | | |
| Internal Seals | | | | | |
| Point CIPP | | | | | |
| Shotcrete and Guniting | | | | | |
| Polymer Coating | | | | | |
| Thermoformed Pipe | | | | | |
| Spiral Wound Pipe (Grouted) | | | | | |
| Spiral Wound Pipe (Ungrouted) | | | | | |
| **Other** *(Specify)* | | | | | |

*The definitions of all the Trenchless Renewal Methods are hyperlinked and explained in the end of the form

**Question 18:** What specification does your company use for Trenchless Renewal Methods specifically for culvert applications? Please provide us a copy.

| Methods | Specifications |
|---|---|
| Cured In Place Pipe (CIPP) | |
| Sliplining | |
| Pipe Bursting | |
| Pipe Reaming | |
| Close Fit Pipe | |
| Panel Lining | |
| Robotic Repairs | |
| Grouting | |
| Internal Seals | |
| Point CIPP | |
| Shotcrete and Guniting | |
| Polymer Coating | |
| Thermoformed Pipe | |
| Spiral Wound Pipe (Grouted) | |
| Spiral Wound Pipe (Ungrouted) | |
| **Other** *(Specify)* | |

*The definitions of all the Trenchless Renewal Methods are hyperlinked and explained in the end of the form

**Question 19:** Please use this space additional information to be considered in our study. Also please explain if your company uses any other type of Trenchless Technology.

## A.4 SURVEY GLOSSARY

### A.4.1 Renewal Methods

**Cured in place pipe (CIPP):** Lining system in which a thin flexible tube of polymer or glass fiber fabric is impregnated with thermoset resin and expanded by means of fluid pressure into position on the inner wall of a defective pipeline before curing the resin to harden the material. The uncured material may be installed by winch or inverted by water or air pressure, with or without the help of a tunneling belt.

**Pipe bursting:** A pipe replacement for breaking the existing pipe by brittle fracture, using force from within, applied mechanically, the remains being forced into the surrounding ground. At the same time a new pipe, of the same or larger diameter, is drawn in behind the bursting tool. The pipe bursting device may be based on an impact molding tool to exert diverted forward thrust to the radial bursting effect required, or by a hydraulic device inserted into the pipe and expanded to erect direct radial force or a static hammer. For a new pipe, generally a HDPE pipe is used, but currently PVC, ductile iron, clay, and GRP is also used. Also know as pipe cracking and pipe splitting.

**Pipe Reaming:** A variation of directional boring called pipe reaming can be used to replace existing clay, asbestos cement, non-reinforced concrete and PVC pipe. A reamer is pulled through the existing pipe which cuts the pipe into small pieces. The pipe pieces are flushed out the bore hole with the drilling fluid.

**Close Fit Pipe:** Description of a lining system in which the new pipe makes close contact with the existing defective pipe at normal or minimum diameter.

**Panel Lining:** Panel Lining is a Modified Sliplining Method. The shape of the culvert is covered by preparing panels and fitting them to the culvert. It can be used to structurally renew large diameter pipes. This method can accommodate different shapes.

**Robotic Repairs:** One of the new Trenchless Technologies. It comprises of a grinding robot and a filler robot. The former removes intrusions, and also mills out cracks to provide a good surface, the filler robot applies an epoxy.

**Grouting:** 1. Filling of annular space between the host pipe and the carrier pipe. Grouting is also used to fill the spaces around laterals and between the new pipe and manholes. Other uses of grouting are for localized repairs of defective pipes and ground improvement prior to excavation during new installations. 2. The process of filling voids, or modifying or improving ground conditions. Grouting materials may be cementitious, chemical, or other mixtures. In trenchless technology, grouting may be used for filling voids around the pipe or shaft, or for improving ground conditions. 3. A method of filling voids with cementitious or polymer grout. Internal Seal: A structural repair method in which basically a new pipe is inserted or cured within the old one.

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

**Shotcrete and Guniting:** Sprayed concrete has terms such as shotcreting and guniting. The two last terms are quite similar however it is believed that guniting is more the spraying of concrete with an aggregate size less than 10mm.

**Point CIPP:** CIPP techniques entail impregnating fabric with a suitable resin, pulling this into place within the sewer around an inflatable packer or mandrel, and then filling the packer with water, steam, or air under pressure to press the patch against the existing sewer wall while the resin cures.

**Polymer Coating:** It is a thermoset coating made up of inert plastic like Epoxies, Urethanes and Ureas, Polyesters which have a high resistance to corrosion, they are applied by trained professionals using special spraying equipments and as per the manufactures specifications.

**Spiral Wound (Grout):** In this process a new pipe is installed inside the existing pipe from the continuous strip of polyvinyl chloride (PVC). The strip has tongue and groove casting on its edges. It is fed to a special winding machine placed in a manhole, which creates a continuous helically wound liner that proceeds through the existing pipe. The continuous spiral joint is watertight. Upon completions of the annulus space between the lining and the existing pipe wall is usually required.

**Spiral Wound (Ungrout):** It is the same process of laying spiral strip as in above Spiral Wound (Grout), but if the lining pipe is closely fitted then there is no need of grouting.

**Thermoformed Pipe:** A type of renewal method which uses poly vinyl chloride (PVC) or polyethylene (PE) pipe that is expanded by thermoforming to fit tightly to fit inside the host pipe.

**Internal Seal:** Internal Seals are used for structural repair pipe joints and missing pipe sections. It can be used in both worker entry and non worker entry pipes.

### A.4.2 Other Definitions

**Abrasion:** Abrasion is the gradual wearing away of the culvert wall due to the impingement of bed load and suspended material.

**Corrosion:** It is a deterioration or dissolution of a material by a chemical or electrochemical reaction with its environment

**Cracking:** A fissure in an installed precast concrete culvert . Corrosion: It is a deterioration or dissolution of a material by a chemical or electrochemical reaction with its environment.

**Debris**: Any material including floating woody materials and other trash, suspended sediment, or bed load moved by a flowing stream.

**Deflection**: Change in the bending radius due to stress, temperature, time and other factors.

**Discharge (Q):** Flow from a culvert, sewer or channel in CFS.

**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

**Erosion (Culvert):** Wearing o grinding away of culvert material by water laden with sand, gravel or stones; generally referred to as abrasion

**Joint failure:** Failures which occur in the joints due to uneven bedding, poorly compacted backfilling operations, or unexpected settlements.

**Hydraulic capacity:** Failure occurring due to insufficient capacity or flooding.

**pH Value :** The log of the reciprocal of the hydrogen ion concentration of a solution. The pH value of 7.0 is neutral; values of less than 7.0 are acid; values of more than 7.0 are acidic.

**Point repairs:** Repair works on an existing pipe, to an extent less than the run between two access points or manholes.

**Repair:** Reconstruction of short pipe lengths, but not the reconstruction of the whole pipe line. Therefore a new design life is not provided. In contrast, in pipe line renewal, a new design life is provided to existing pipeline system.

**Replacement:** All aspects of upgrading with a new design life for the performance of the existing pipeline. Includes rehabilitation and renovation.

**Spiral lining:** A technique in which a ribbed plastic strip is spirally wound by a winding machine to form liner, which is inserted into a defective pipeline. The annular space may be grouted or the spiral liner expanded to reduce the annulus and form a close fit liner. In larger diameters, the strips are sometimes formed into panel and installed by handful stuff. Grouting the annular space after installation is recommended.

**Trenchless Rehabilitation:** It is the process of Upgrading to a new design life by forming a new pipe within the existing pipe with minimum or no excavation.

**Trenchless methods:** Also no-dig techniques for underground pipeline and utility construction and replacement, rehabilitation, renovation (collectively called renewal), repair, inspection, leak direction, and so on, with minimum r no excavation from the ground surface.

**Utility tunneling:** It is general approach of constructing underground utility line by removing the excavated soil from the front of cutting face and installing liner segments to form continuous ground support structures. The product pipe is then transported and installed inside the tunnel. The annular space between the liner and the pipe is usually filled with grout.