THEORETICAL FEASIBILITY STUDY FOR A CONCEPTUAL APPROACH TO TRENCHLESS REPLACEMENT OF CULVERTS

by

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ABSTRACT

THEORETICAL FEASIBILITY STUDY FOR A CONCEPTUAL

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OF CULVERTS

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Culvert damage and collapses and their renewal alternatives are a raising concern in today's infrastructure topics. In most cases damages are irreversible; however, in many cases opportunities exist to correct and renew. While conventional open-cut construction brings inconvenience to the public, trenchless technology brings a greener, reliable and more socially acceptable alternative to renew culverts. Considering the strong dependency on highway transportation by the American lifestyle, collapses of culverts in major roads may produce chaotic traffic redirections. To reduce this risk, this research sets a path for a construction and feasibility study on a new culvert replacement method based on an exploratory means; therefore, the specific objective is to design and estimate construction costs for a conceptual trenchless method and determine its feasibility.

With a comprehensive literature review for culverts and its engineering principles the author introduces the topic while investigating also on the factors that lead to culvert underperformance. Preceding a general study on cellular sheet piling, the thesis investigates on trenchless technologies and other tunneling methods capable of replacing culverts. The results of the literature search direct the author to develop a new method, potentially suitable for replacing culverts. By combining pipe ramming, pipe jacking, cellular sheet piling and pipe roofing altogether, the method encases the host culvert allowing its later removal. The installation steps are formulated along with a general recommendation on equipment and materials. Advantages and limitations are explained for the process giving the reader a broader view of the proposed method. To start demonstrating the feasibility and other factors for the new methodology, a survey was conducted among the industry which resulted in a positive acceptance. The survey also assists the researcher on topics such as advantages and limitations, feasibility, crew sizes, project durations, and future research recommendations. In an ultimate step towards feasibility and cost estimation analysis, a theoretical detail cost estimation for the proposed methodology is performed. A replacement project on an imaginary two-way road with one single line in each direction is studied and cost estimated. The backbone of the cost estimation is the combination of the results of the survey and information from construction cost databases.

In conclusion, this research proved the economic feasibility of the new method by successfully analyzing its direct costs. The direct costs for the proposed methodology seem high; however, they prove the economic feasibility when the social cost savings by trenchless technologies are considered; also, when comparing the estimated costs with other similar technologies, the new methodology resulted less expensive.

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CHAPTER 1

INTRODUCTION AND RATIONALE

1.1 Introduction

Culvert structures and materials vary widely as well as their use; nevertheless, culverts perform better when are used for stream crossings in highway and railroad applications (FHWA, 1986). Damage on culverts is irreversible in many cases. In most situations, opportunities exist for corrective measures (Gabriel & Moran, 1998); however, these measures are not applicable in all cases. The need of replacing culverts may be sometimes imperative; to cope with this situation, newer construction technologies such as the Trenchless Technologies are currently available. Trenchless technologies provide greener and reliable solutions to replace culverts than the open-cut counterpart. Less traffic disturbance, reduced social cost and better production rates are some of the reasons why trenchless technologies are becoming an alternative against traditional open-cut. Technical studies in trenchless replacement of culverts are limited; only field trials and construction case studies were found for some methods, with no substantial scientific research regarding feasibility, sequence of installation, safety, cost estimation, material selection and other engineering fundamentals. In consequence, there are opportunities to research on trenchless replacement of culverts due in part to the lack of scientific literature and research.

1.2 Background of the Study

Over the years, culverts have received less attention than bridges and other structures; in part because there are less visible for drivers; consequently they are easy to put in an out of mind situation, particularly when they are performing adequately (FHWA, 1986). In this section the research explores some drawbacks of culvert underperformance, the current efforts on culvert inspection and the culvert failure problematic.

When culverts are underperforming, culvert failures are sudden and without many visible symptoms. As with any structure the cost of replacing a culvert is high; and when disruption of the traffic is considered, the conventional open-cut alternative becomes undesirable (TricTools, 2009). Construction activities cause more economic impact where more traffic is present. Performing a culvert replacement activity by open-cut is especially not recommended in urban areas where traffic congestion is highly susceptible.

Dependency on highway network and motor vehicles is a must for many American citizens as the Transportation Research Board (TRB) denotes “the American lifestyle is strongly dependent on highway transportation” (TRB, 2008). The Bureau of Transportation Statistics (BTS) shows continuing increases in highway congestion for many urban areas of the United States. In 2007 approximately 83% of the all the United States households had a vehicle and 86.5% of workers commute to their workplaces by car (BTS, 2008). “Americans use personal vehicles for approximately 87% percent of daily trips and 90% percent of long distance trips” (TRB, 2008). It can be speculated that a failure of a major culvert may cause chaotic redirection of traffic in both urban and rural settings; it may be also costly and hazardous to the public (FHWA, 1986). Figure 1-1 shows a failure of a major culvert in the interstate highway network, which resulted in a threatening situation.

Figure 1-1 Culvert Failure on Interstate-88 June, 2006 (FHWA, 2007)

Other authors such as Perrin (2006) explain that the most visible assets on roadways are roads and bridges because they are easily assessable for inspection and management. As a result of this, thousands of aging culverts under the roadways are often overlooked. This leads to a preliminary conclusion -culverts are a nation's forgotten asset. Figure 1-2 shows that 23 of the states and territories of the U.S. do not use any type of management system for culverts; one of those states not is the state of Texas. It is imperative to understand the cost of inspecting, maintaining and replacing culverts on time is an added economic burden to agencies, but on the long run, it may represent cost savings over the emergency repair of a failing culvert (Perrin, 2006).

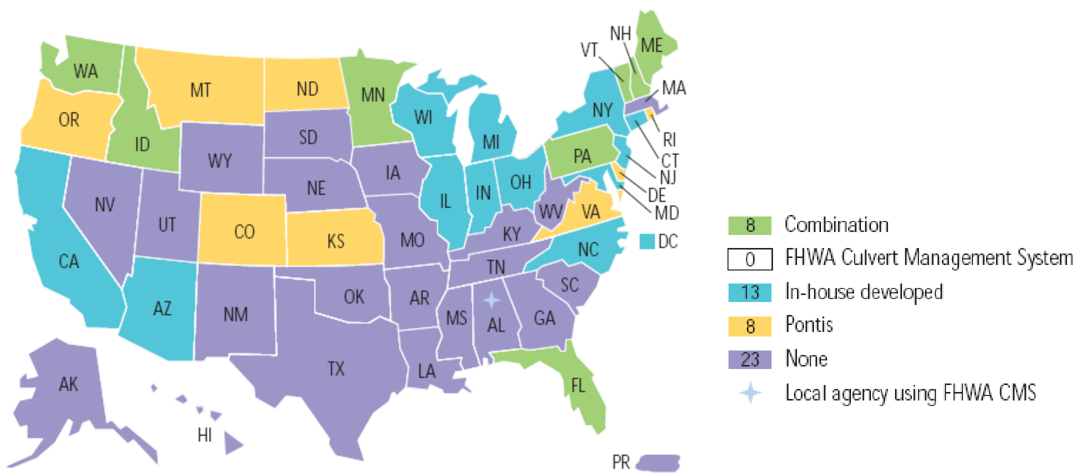

Figure 1-2 Usage of Culvert Asset Management Systems (FHWA, 2007)

In the U.S. Federal Highway Administration (FHWA) corporate website, a database named the National Bridge Inventory (NBI)[1] counts bridges by structure type and classifies culverts by state. In this database, culverts are classified differently from bridges; as the

[1] "The NBI is a collection of information (database) covering just under 600,000 of the Nation's bridges located on public roads, including Interstate Highways, U.S. highways, State and county roads, as well as publicly-accessible bridges on Federal lands. It presents a State by State summary analysis of the number, location, and general condition of highway bridges within each State", it includes culverts as well as bridges. (FHWA, 2008).

USDOT[2] explains, culverts are structures which do not have a deck, superstructure, or substructure, but rather are self-contained units located under roadway embankment. The NBI database of 2008, speculates on the total number of culverts in the U.S., this agency estimates a total of 127,877 for the whole territories. Of these culverts approximately 8,856 are classified as deficient in both structurally and functionally behaviors, see Figure 1-3. While assuming the NBI total number of culverts in Texas and dividing them by the total working days per year in the U.S., (261 days) the rate of renewal for this state yields a high and alarming rate of approximately 5 culverts per day. Of course this rate assumes having one contractor renewing damaged culverts and also assuming one culvert is renewed per day. This simple calculation may demonstrate the need and the urgency in culvert renewal and replacement while speculates about the approximate number of deficient culverts in Texas.

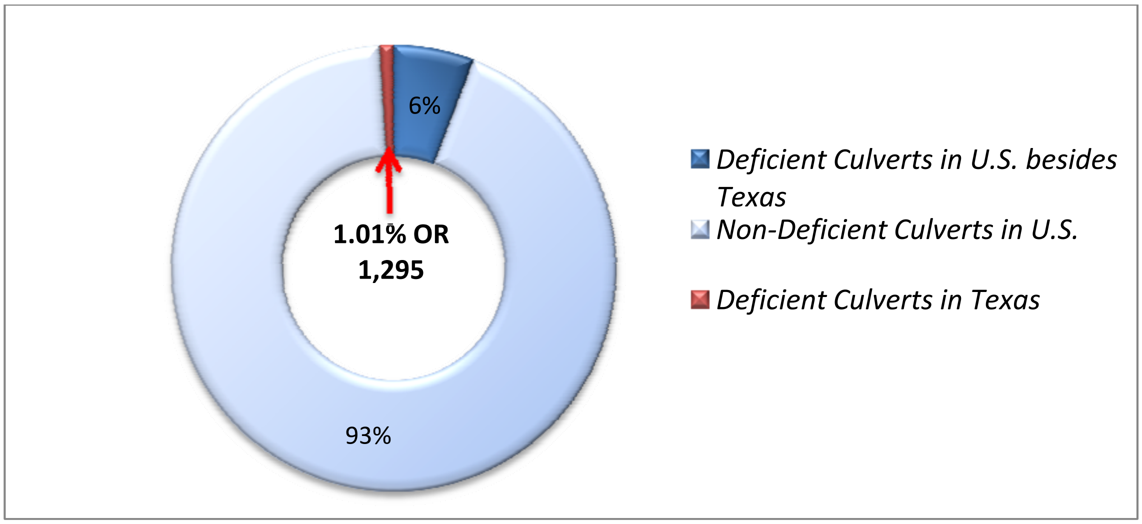

Figure 1-3 Deficient U.S. Culverts in 2008 (Source: NBI)

This alarming rate of replacement is high and a plan address it must be carefully reviewed. Replacement costs of culverts at emergency rates are an issue, as Perrin (2006) explains: "Without a plan followed by action, failing culverts will have to be replaced at

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[2] The United States Department of Transportation (USDOT) is an entity which often uses above database to produce a report to the U.S. congress about the condition and performance of bridges and culverts.

emergency rates instead of normal rates." All this in conjunction with the lack of an adequate asset management strategy and a wide array of replacement approaches may not support the reduction of culvert replacement costs in the near future. Considering need for culvert renewal and replacement, the best approach to address it may be using trenchless technology methods, and more precisely using in-line replacement alternatives. The advantages of replacement via trenchless are plenty, such as the reduction of social costs and overall cost of the project. These statements had been carefully discussed by other authors (Najafi, 2005).

Much work has been done in the area of in-line replacement of culverts, particularly by manufacturers; however, due to urgency and large amount of work, further research and development is required (Chapman, et al. 2007). Although some trenchless technologies, such as pipe bursting, have been adapted to serve as in-line replacement methods for culverts, most of them have been rarely used or proven. Only field trials and construction case studies were found in the literature.

1.3 Problem Statement

Culvert failure must be recognized as an immediate and unexpected threat to public safety (Wissink, et al, 2005). On one hand, failures of structural type may result in sinkholes, which are equivalent to a bridge collapse (Perrin, 2006). On the other hand, failures of functional type may result in blockage by debris and sudden floods; which fortunately has no equivalent in bridges. During large storm events, culverts have a high probability of blocking; culvert openings of more than 20 ft (6.1 m) are unlikely to block, however, culverts with openings of less than 20 ft (6.1 m) are likely to blockage (Rigby, et al. 2002). In a close-up view, inspections and inventories made by Washington County, Oregon, estimated a total of 3,000 culverts in their 1,300 miles of roads; these investigations revealed the need for increased emphasis on critical but often hidden elements of the county's roadway infrastructure (Washington County, 2009). Culvert's catastrophic events may also cause losses of time, money and lives. For instance, Ayala and Brown (1997) explains that in Chile, a storm event caused the failure of a culvert in a major highway leaving "an open pit, approximately 20 m (65.6 ft) wide by 18 m (59 ft) deep... Seven vehicles fell into this created open pit before the traffic was stopped. As a consequence, 27 persons died."

In relation to the topic of culvert replacement via trenchless, some conceptual and practical voids exist. For instance, the use of microtunneling for replacing of culverts is neither widely accepted nor scientifically investigated. The cost of using a trenchless replacement methods and the diversity of them is also a big issue. Due to the high variety of methods, the calculation of cost savings between each method is difficult. Not many trenchless replacement methods for culverts have been developed in recent years, there is a small variety of methods to chose; moreover, they are not well recognized, used or investigated. A solid and broad research on this topic will aid contractors, DOTs, academics, and other professionals to choose or focus their attention to the new and maybe less costly options.

In summary and without going beyond, the problem can be easily established. As Clark, et al. (1977) explain, a problem establishes the existence of two or more juxtaposed factors which, by their interaction, produce:

1. An enigmatic or perplexing state
2. Yield an undesirable consequence, or
3. Result in a conflict which renders a choice among available alternatives

Given the fact that of the factors affecting culvert replacement, the three yielding factors of Clark, et al, correspond to the culvert issue as follows:

1. The culvert failure problematic is in "an enigmatic or perplexing state"
2. Which almost always yields "an undesirable consequence" such as collapses
3. Resulting "in a conflict which renders a choice from among available alternatives" such as the trenchless technology alternatives

1.5 Objectives of the Study

1.5.1 Specific Objective

The specific objective of this thesis is to design, and estimate construction costs for a conceptual culvert replacement method using trenchless technology theory. The new tool may combine various features of current trenchless methods. This thesis is a qualitative research type focused on exploratory research, due in part to the limitations on the source of knowledge (Naoum, 1998). For Zikmund (1997), exploratory research may be conducted for three interrelated purposes: diagnosing a situation, screening alternatives and to discover new ideas (Zikmund, 1997).

1.5.2 Other Objectives

- Better identification of the culvert replacement problematic
- Search the most up to date literature on the thesis topic
- Identify and define the market for the new development
- Study the feasibility of the new development
- Compile the findings of the proposed thesis to establish recommendations for future research

1.6 Scope

This research is limited to the development of a methodology to replace culverts via trenchless and theoretically estimate its bare costs. Only bare installation costs are studied, which means that costs incurred for general conditions, overhead and profit are not estimated. Due to time constraints, no physical model is built or analyzed, as well as no structural design or geotechnical investigation is considered; however, dimensions and materials for some components will be detailed due to the need of estimating construction costs.

This research focuses on culverts functionally and structurally obsolete in need of cross sectional upsizing but not totally collapsed. This thesis analyzes structures of less than 20 ft (6.1

m) in diameter for circular and elliptical culverts, and 20 ft (6.1 m) diagonally for rectangular culverts. It is limited to installations of no more than 100 ft (30.5 m) in congested two-way roads.

1.7 Methodology

After investigating the cellular sheet piling process, pipe ramming process, pipe roofing, and other similar methods, the author defines the best approach possible to the construction process and its methods. The author formulates the equipment needed and the steps of a culvert replacement undertaking. A detailed sketch of a made-up replacement project is formulated to perform quantity takeoff. Based on the author knowledge of cost estimation and the general knowledge acquired from the industry in industry related conferences, the author executes a theoretical cost estimation for the new development.

The costs for each of the quantities are generated from standardized construction cost databases such as R.S. Means. All the cost estimation work is developed and presented using a spreadsheet software application. Due to the theoretical environment of the cost estimation analysis, only the installation costs or bare costs of the new method will be investigated; therefore: overhead and profit, and other rising cost variables will not be investigated. A simple cost comparison to other similar technologies assists the researcher on determining the feasibility of the proposed methodology.

1.8 Expected Outcomes

The expected outcomes are divided in three major areas. From the academy point of view, this investigation aims to invent and study the feasibility of a new in-line replacement method for culverts. With this study, the author expects to generate knowledge on topics related to: costs estimation, general procedures for trenchless technologies, or reliability of in-line replacement of culverts.

From the general public and safety point of view, this study aims to address the public attention to catastrophes and/or lives taken by culverts, sudden culvert collapse may cause higher reconstruction costs. As Wissink, et al, explains, failures often lead to increases in replacing costs, flooding, roadway damage, interruption of traffic, and even fatal accidents (Wissink, et al. 2005).

The researcher also believes on the possibility of economically develop new or improved methodologies or devices to replace culverts. The significance of this topic increase when the present infrastructure construction trend considered. Other outcomes of the present study are listed as follows.

- An invention of a successfully new culvert renewal method via trenchless, economically accessible for DOTs, environmentally friendly, safe and productive
- A theoretical cost estimation analysis for the new method based on detailed drawings for a specific situation
- A comprehensive analysis of the current technologies available to replace culverts
- A simple but yet meaningful analysis of the need for replacing culverts in the U.S. and especially in Texas

1.9 Chapter Summary

Culvert damages and collapses and their renewal alternatives are a raising concern in transportation agencies nowadays. Corrosion and abrasion damage to culverts is irreversible in most cases; however, in many cases opportunities exist to correct and renew. Conventional construction alternatives most of the times offer inconveniences to the public, which ultimately raise social costs. To reduce these costs, trenchless technologies are currently being used as a set of greener and reliable methods capable of rehabilitate or replace culverts.

Traditionally culverts have received less attention than other infrastructure elements due to their out-of-sight out-of-mind nature, particularly when they are performing adequately. In most cases underperforming culverts are rehabilitated; however, sometimes they need upsizing. Considering the strong dependency on highway transportation by the American lifestyle the likelihood of chaotic traffic redirections due to a major culvert collapse is predictable. Based on unrealistic culvert inventories (FHWA, 2008), the state of Texas has approximately 1% of deficient culverts in need of either rehabilitation or replacement. In order to reduce this alarming rate, this research sets a path for a feasibility study on a new culvert replacement method based on an exploratory research with three interrelated purposes: diagnosing a condition, screening options and inventing or reinventing construction methods.

CHAPTER 2

LITERATURE REVIEW

2.1 Definition and Overview of Culverts

The American Association of State Highway and Transportation Officials (AASTHO) defines a culvert as a short conduit that conveys surface water across or from the road right-of-way. In addition to this hydraulic function, it must also carry construction and road traffic and earth loads (AASHTO, 2007). Culverts are constructed from a wide viriety of materials and are available in many different shapes and configurations. Culverts as distinguished from bridges, are covered with embankment and are surrounded of structural material around the entire perimeter, some are supported on spread footings with the streambed serving as the bottom of the culvert (USDOT, 1996). A typical culvert is composed of the following elements as shown in Figure 2-1.

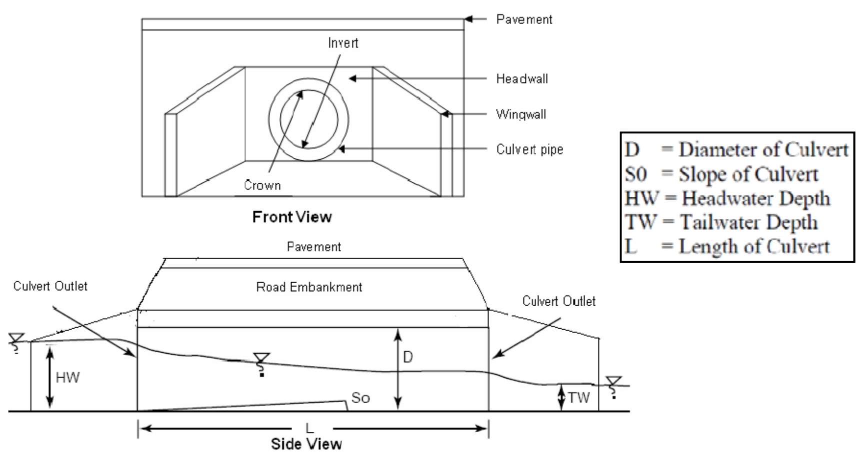


Figure 2-1 Typical Culvert Components (Najafi, et al, 2008)

Culverts are usually considered unimportant structures; however, they are of great importance to adequate drainage and integrity of the road (AASHTO, 2007). Culverts may be cost-effective substitutes for bridges at some sites; however, they often do not provide clearance for navigation, debris, ice, and fish passage as compared to bridges. The selection of an adequate culvert for a site is dependent on numerous factors.

2.2 Culvert Design Considerations

A wide arrange of engineering and non-engineering principles are considered in the design process of a culvert. A list of the most commonly factors based on Norman, et al, (2001) is illustrated on Table 2-1. This section discusses the applicability of these considerations into the culvert design process.

Table 2-1 Common Engineering and Design Considerations

Engineering and Design Considerations	
Hydrology	Protection Type
Hydraulics	Location
Structure	Roadway Data
Geotechnical	Economy
Material	Regulatory and Arbitrary Constraints
Shape	Other Factors

2.2.1 Hydrology

Water and its related resources are of important consideration while in the planning and locating highways and their appurtenant structures. All possible effects that a roadway structure may have on existing drainage patterns, river characteristics, potential floods hazards, the environment in general, and the effects if the river on any road, should be considered (AASHTO, 2007). For this reason hydrology or hydrologic analysis for culvert design, should involve the estimation of a design flow rate based on climatological and watershed characteristics (Normann, et al, 2001). The hydrologic analysis often includes statistics to estimate the return period concept which is referred to the frequency of occurrence of rare events such as floods. Due to higher risks involved, expensive culvert designs may demand extensive hydrologic analysis (Normann, et al, 2001). Hydrologic analysis may also involve the determination and use of concepts such as peak design flow, check flows, hydrographs and hydraulic cycle.

2.2.2 Hydraulics

Hydraulic design may determine whether the barrel of a culvert may flow full over all of its length or partially full, in any case, full flow in a culvert is rare and generally at least part of the barrel flows partly full. Water surface profile calculations are the only way to accurately determine how much of the culvert barrel flows full or in pressure. A pressurized flow may be caused by a high downstream water surface elevation or a high upstream water surface elevation. A free surface flow, open channel flow or partly full flow in the culvert barrel may be categorized as subcritical, critical or supercritical, which is determined by evaluating the Froude number. One special type of free surface flow is called “just-full flow” which is a special condition where a pipe flows full with no pressure. Regardless of the flow conditions, culvert hydraulic design is based on how the flow can be controlled; which is divided in inlet control and outlet control (Normann, et al, 2001).

2.2.2.1 Inlet Control

Occurs when the culvert barrel is capable of conveying more flow than the inlet will accept (Normann, et al, 2001). When a culvert functions under the inlet control or entrance control, the flow and the associated headwater upstream depth are primary functions of the culvert entrance. In inlet control design, the culvert capacity is determined by the entrance opening area and the culvert never flows full. Figure 2-2 shows a typical inlet control flow section.

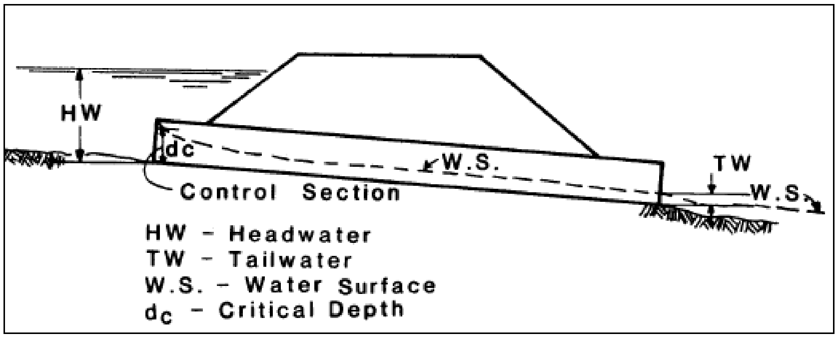


Figure 2-2 Typical Inlet Flow Control Section (Normann, et al, 2001)

2.2.2.2 Outlet Control

Occurs when the culvert barrel is not capable of conveying as much flow as the inlet opening will accept; then the control section for the culvert barrel is located downstream. In these conditions only subcritical or pressure flows can exist. Unlike inlet control, the culvert capacity is determined by the geometry and hydraulic characteristics (Normann, et al, 2001). While designing outlet control, downstream protection must be considered against scouring or erosion (Najafi, et al, 2008). Figure 2-3 shows two typical outlet control sections, pressurized or submerged flow and subcritical or unsubmerged flow.

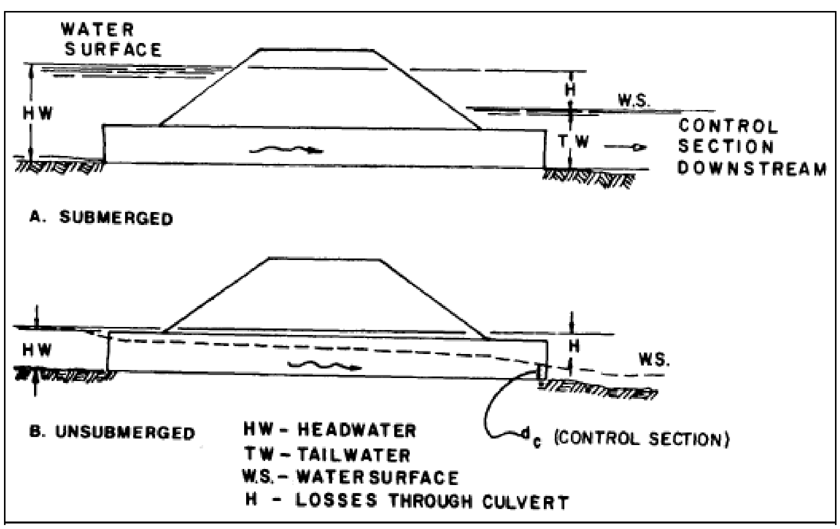


Figure 2-3 Typical Outlet Flow Control Section (Normann, et al, 2001)

2.2.3 Structure

The structural design of a culvert must be carried to ensure that the culvert is strong enough to carry the imposed traffic loads or earth loads that act upon it (Ballinger and Drake, 1995). The structural aspect of a culvert barrel can be categorized as flexible behavior or rigid behavior.

The flexible behavior criteria is based on the assumption that the culvert barrel and the surrounding soil act as one structure; therefore, allowing the reduction of the vertical diameter and the expansion of the horizontal diameter. In this manner vertical loads are transmitted to the surrounding soil (Najafi, et al, 2008).

The rigid behavior theory assumes that the barrel is so rigid that can carry vertical loads for itself without interaction of the surrounding soil; therefore, when vertical loads are applied to a rigid culvert, zones of tension and compression are created in the culvert structure (Najafi, et al, 2008).

2.2.4 Geotechnical

The conditions of the foundations must be investigated specially for larger culverts, in particular factors such as allowable bearing pressure, bedding requirements, groundwater table, slope stability, erosion control and rock excavation. These factors should also apply to culvert end treatments, approaches and culvert barrel (Ballinger and Drake, 1995). In many cases, erosion and scour at a culvert crossing are damaging factors to the embankment, the culvert structure or the downstream channel (AASHTO, 2007); in these cases end treatments such as rip-rap can be used.

2.2.5 Material

The selection of the most suitable material for a culvert is dependent upon several variables such as, structural strength, hydraulic roughness, durability, corrosion resistance and abrasion resistance and bedding conditions (AASHTO, 2007). The three most common materials used for culverts are concrete, corrugated aluminum, and corrugated steel (Normann, et al, 2001); however, culverts may be present in other materials like vitrified clay, masonry, stone, plastic, bituminous fiber, cast iron, wood, and stainless steel. Figure 2-4 Shows a culvert made of stone masonry.

Figure 2-4 Stone Masonry Culvert in Mexico

2.2.6 Shape

Even though numerous cross-sectional shapes are available, the circular shape is the most common shape for a culvert because it is hydraulically and structurally efficient under most conditions. A culvert shape selection should consider construction cost, potential for clogging by debris, limitations on headwater elevation, fill height, and hydraulic performance of the design (AASTHO, 2007). The most common sectional shapes for culverts are illustrated in Figure 2-5 (Normann, et al, 2001). However, other configurations also include multiple barrels of the illustrated shapes (Najafi, et al, 2008). For instance, in the case of box culverts, it is usually more economical to use a multiple structure formation than a wide single span; however, in some locations multiple barrels have a tendency to retain debris (AASHTO, 2007).

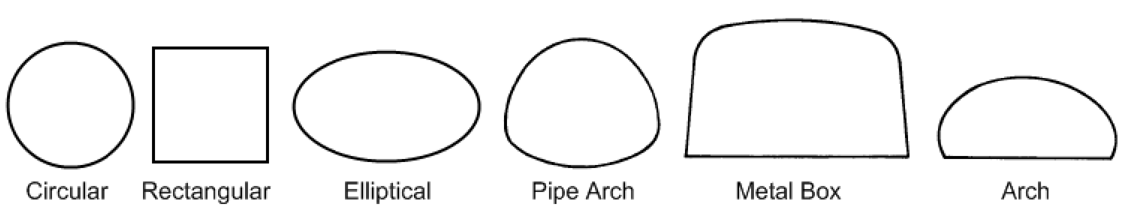


Figure 2-5 Common Culvert Shapes

2.2.7 Protection

Culvert barrel protection is used to extend the service life of the structure. In general, most culvert materials exposed to seawater require some type of barrel protection to assure adequate service life. Protection of metal culverts from corrosion usually consists of bituminous fiber-bonded coating or mill-applied thermoplastic coating (AASHTO, 2007). A summary of the different culvert protecting coatings is listed on Table 2-2.

Table 2-2 Summary of Culvert Protecting Coatings

Material	Description
Zinc Galvanizing	Application of a thin layer of Zinc to steel
Aluminizing	Application of a cover layer of Aluminum or Aluminum Paint
Asphaltic Coatings	Application of an asphaltic layer on the outside of a pipe
Polymeric Sheet Coatings	A protective coating of plastic polymer resins with other materials
Concrete Coatings	A protective concrete layer on the outside of a pipe
Asbestos Bond Coatings	Protective coating containing asbestos fibers in spray or felt
Coal Tar Resin	A black liquid obtained as a by-product of coal carbonization
Thermoplastic Coatings	Powders that mix to create a coating with physical properties

The highway drainage guidelines from AASHTO (2007) explain that end treatments also protect the culvert from exterior hazards like embankment erosion at the culvert inlet or erosion at the downstream of the culvert outlet. Headwalls, wingwalls and slope protection are commonly used at culvert entrance to prevent erosion and/or piping. Toe walls, rip-rap, armoring, energy dissipators, and preformed sour holes can be designed to protect the culvert outlet (AASHTO, 2007). Headwalls and wingwalls also make the culvert more efficient by facilitating the flow.

2.2.8 Culvert Appurtenances and End Treatments

These added structures are functional portions that improve flow and integrity of the culvert. The principal inlet structures are shown in Figure 2-6. The principal outlet structures are: energy dissipaters, aprons, and fish passage devices. Other types of configurations include: skewed culverts, mitered culverts and projecting culverts (Najafi, et al, 2008). Inlets are usually considered when the culvert is operating under hydraulic inlet control because they increase the overall hydraulic performance of the culvert (Fwa, 2006).

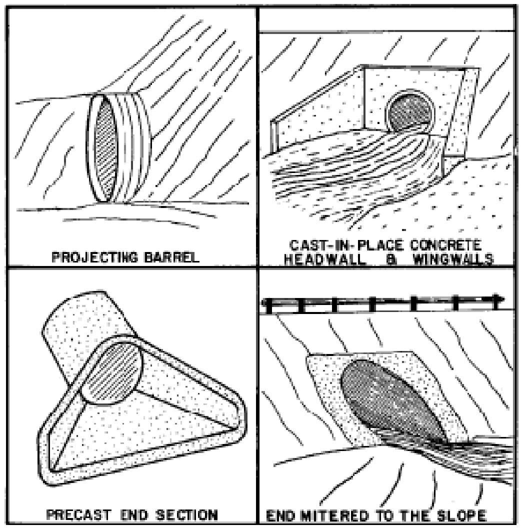


Figure 2-6 Four Typical Inlet Types (Normann, et al, 2001)

2.2.9 Location

The design of a culvert also requires the consideration of the culvert location. Culvert location compromises the horizontal and vertical alignment of a culvert with respect to the stream and the road (AASHTO, 2007). Ideally, a culvert should be located in the existing channel bed to minimize costs associated with excavation and channel work. However, it is not always possible (Normann, et al, 2001). If a well defined stream bed exists, the bed of the culvert should have the same inclination as that of the stream, otherwise, either the inlet or outlet will clog depending on whether the culvert slope of the culvert is greater or lesser with respect to the stream (Hool and Thiessen, 1917). In any case, culvert barrels should be placed in the existing channel bed because is the cheapest location since it involves least earthwork and re-routing of the water. Exceptions may include mountainous areas where the channel may require an unusually long culvert, or winding channels that need a straight culvert (Fwa, 2006).

2.2.10 Roadway Data

The roadway data may be the first piece of information a designer has because they can be easily obtained from preliminary roadway drawings or from standard details on roadway sections. Culvert cross section, culvert length and the longitudinal roadway profile may be sub-products of the roadway data evaluation (Normann, et al, 2001).

2.2.11 Economic Consideration

Factors such as construction costs, estimated service life, maintenance cost, replacement cost, risk of failure and risk of property damage must be revised for new construction of culverts or major repairs (Ballinger and Drake, 1995). Many are the benefits of constructing a larger capacity culvert to accommodate floods of all types that may affect a culvert along its design life; moreover, the economic effects of a catastrophic culvert collapse are normally outweighed by initial construction costs. Design flows for culverts are calculated based on the importance of the road with little attention to economic factors; however, more rigorous investigations are being carried out for large culvert installations (Normann, et al, 2001). In summary, it is important to consider that, the most economical culvert installation is the one with less total cost over the design life period (Ballinger and Drake, 1995).

2.2.12 Regulatory and Arbitrary Restrictions

As Normann, et al, explains, the requirements for the National Flood Insurance Program are a major consideration when designing a culvert. Some state and local agencies place arbitrary constraints on the headwater produced by a culvert structure (Normann, et al, 2001); a requirement that can be closely connected to fish passage assurance. Lastly, fish passage should be always assumed regardless of the stream size (ODOT, 2005).

2.2.13 Other Considerations

In addition to the engineering and non-engineering aspects considered above, there are other factors that engineers and designers should be cognizant, such as: maintenance, safety, environmental, fish passage, resistance to flotation and constructability (Ballinger and Drake, 1995).

2.3 Culvert Underperformance

A wide variety of problems affect culverts; they are often classified depending on either hydraulical or structural problems. Among these problems are: inadequate flow capacity, scour, erosion of streambed and embankments; however, corrosion and erosion are the two most common (Ballinger and Drake, 1995). A complete list of the factors influencing culvert performance is explained in the following section. Some of this factors may lead to culvert underperformance, which is closely related to the rate of deterioration and the service life of an asset. As Najafi, et al, (2008) explains, non-inspected and non-maintained culverts deteriorate faster than expected due to various changing environmental, hydraulic and social conditions, which often lead to emergency repairs or rehabilitations as shown in Figure 2-7.

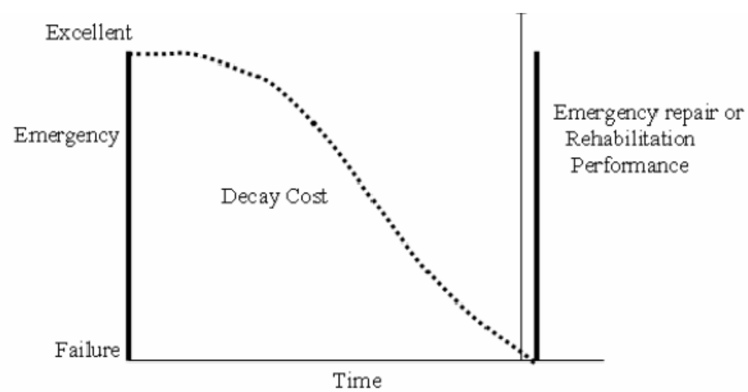


Figure 2-7 Asset Deterioration Curve (Najafi, et al, 2008)

2.3.1 Factors Influencing Service Life and Performance

A wide variety of environmental, geotechnical, structural and service-life-related factors influence the performance of culverts. Service life of culverts can be affected by factors such as damage due to debris or erosion (AASHTO, 2007). One of the culvert's most affecting factor is corrosion, which relates to the destruction of the pipe material by chemical actions (AASHTO, 2007).

Table 2-3 summarizes the factors that influence culvert performance, which in some cases may influence failures in culverts.

Table 2-3 Summary of Factors Influencing Culvert Service Life and Performance

FACTORS				
Durability	**Structural**	**Environmental**	**Geotechnical**	**Design**
Corrosion	Joint Separation	Debris	Ground Settlement	Size
Abrasion	Misalignment	Flash Floods	Earthquakes	Gradient
Streambed Erosion	Seam Defects	Landslips	Soil Type	Depth
-	Transverse Cracks	Erosion (Embankment)	Water Table	-
-	Longitudinal Cracks	Frost Load	-	-
-	Deflections	Frost Heave	-	-
-	-	Wall Temperature Gradient	-	-

2.3.2 Underperforming Culverts

They are described as structures not fully servicing their design flows and in need of a major readjustment. By using the classification system of the National Bridge Inventory from FHWA (FWHA, 2008) the author divides the underperforming culverts into two groups: structurally deficient culverts and hydraulically deficient culverts (also called functionally deficient culverts). Hydraulically deficient culverts may be prone to flood nearby areas. Hydraulically deficient culverts have either under-designed hydraulic capacity or under-estimated design flow. Structurally deficient culverts do not provide sufficient stability for the structure to continue providing service; however, it might be difficult to establish when a culvert is structurally deficient.

2.4 Current Trenchless Technology Renewal Approaches

When related to culverts, trenchless technology consists of a set of methods, materials and equipment for inspection, stabilization, rehabilitation, replacement of existing culverts, and installation of new culverts with minimum excavation of the ground surface (ODOT, 2005). Renewal is a term often used to encompass both rehabilitation and replacement procedures (Salem, et al, 2008). The most common renewal methods applicable to culverts can be divided into two groups, in-line replacement and liners as shown in Table 2-4.

Table 2-4 Trenchless Renewal Methods for Culverts

TRENCHLESS RENEWAL METHODS FOR CULVERTS									
In-Line Replacement		Liners							
Pipe Bursting /Pipe Splitting	Microtunneling	Cured-In-Place Pipe (CIPPP)	Shotcretting	Thermo-formed Pipe	HDPE Grout-In-Place Pipe	Spiral Wound	Sliplining	Coatings and Linings	Panel Lining

2.4.1 Liners

When the extent or type of damage on a culvert barrel severely limits the structural strength of the functionality and cannot be easily repaired, trenchless rehabilitation procedures should be considered (Ballinger and Drake, 1995). Liners are often used to cope with this need; they are used to form a new culvert barrel within the host barrel (Najafi, et al, 2008). This section presents a brief explanation of the listed liner methods.

2.4.1.1 Cured-In-Place Pipe (CIPP)

CIPP is a one of the most used methods in trenchless technology for both structural and nonstructural purposes in potable water pipelines, sewers and gas pipelines (Najafi and Gokhale, 2005). In the CIPP renewal process, a culvert is lined in its interior with a continuous fabric sleeve, which is inserted into the culvert using the inversion method or using a winch. The fabric sleeve should be impregnated with a thermosetting liquid resin material that acts as a grout. After inserted, the impregnated fabric is cured using heat until the resin hardens and attaches the fabric to the existing culvert. One of the most remarkable advantages of this type of renewal is the lack of joints in the liner, which reduces the effects of corrosion and abrasion in the streambed of the culvert(Najafi, et al, 2008).

2.4.1.2 Cement Grouting, Gunite and Shotcreting

Cement grouting is also known as cement mortar lining and is often used to prevent corrosion on iron pipes (Najafi, et al, 2008). Cement grouting consists of a mixture of slurry of cement, water and other material such as sand, bentonite or chemical accelerators. The cement mortar lining is generally thin, making it possible to install using a rotating machine. Shotcrete and gunite are often used for large-diameter culverts (Najafi and Gokhale, 2005). If reinforcing steel bars are applied, the structural strength of the culvert is improved; however, the culvert diameter may reduce significantly (Najafi, et al, 2008).

2.4.1.3 Thermoformed Pipe

This liner method consists on the on-factory-deformation of polyvinyl chloride (PVC) or polyethylene (PE) pipes, and the on-site-re-formation of them inside a culvert using heat. Using this process a tight fit between the culvert and the plastic liner is produced and without the use of grouts. This technique is useful to address problems such as corrosion or abrasion in culverts (Najafi, et al, 2008). One of the main advantages of thermoformed pipe renewal is its rapid installation due to the in-factory manufacturing of the liner (Salem, et al, 2008).

2.4.1.4 Sliplining

Since the 1940's sliplining has been one of the simplest forms of trenchless renewal, used for structural and nonstructural purposes. Installation of flexible pipes of up to 10% smaller diameter compared to the host piped is possible by pulling or pushing the new pipe into the deteriorated culvert barrel. The annular space created between the new pipe and the host culvert barrel should be always grouted. Glassfiber Reinforced Polyester (GRP), PVC and PE are the most commonly used materials; other pipe materials can be used; however, caring to select a material more resistant to the environment than the original. (Najafi and Gokhale, 2005). Although sliplinging reduces the cross-sectional area of the culvert, a smoother interior surface may help to accommodate the design flow by increasing high flow speeds (Najafi, et al, 2008); nevertheless, high flow speeds in the culvert barrel may not facilitate fish passage.

2.4.1.5 Coatings and Linings

The procedure of coatings and linings is often called "invert paving"; which is a common procedure to protect deteriorated culvert barrels from further corrosion or abrasion deterioration.

Invert paving, uses liquid and solid mixes of chemical compounds to create a liquid epoxy, capable of hardening and withstand pressures. One of the main advantages of invert paving is its low cost and the low special equipment requirements (Salem, et al, 2008).

2.4.1.6 Panel Lining, Spiral Wound, Grout-In-Place Pipe

As described by Najafi and Gokhale, these three methods are all modifications to the original sliplining process where a new pipe fits closely with the shape of the existing barrel. Panel lining and grout-in-place pipe are common methods for large diameter pipes; spiral wound is commonly applicable for small diameter culverts but can be certainly used for large diameter as well. Panel lining is sometimes specifically used to renew large diameter noncircular drainage structures (Najafi and Gokhale, 2005).

The grout-in-place pipe method is also called form-in-place pipe; this process comprises two or more thin sheets of High-Density Polyethylene (HDPE). One of the sheets (the preliner) rests on the surface of the damaged barrel while the other (the inliner) provides studs, creating an annular space. Inside the two sheets, a special high-strength, nonshrink, proprietary grout is inserted. The final result is a continuous rigid liner that fits tight to the damaged barrel (Najafi and Gokhale, 2005).

Spiral wound pipe renewal lines an old and damaging barrel by spirally winding PVC strips using a special winding machine at the jobsite (Najafi, et al, 2008). In spiral wound pipe, the annular space created between the PVC strips and the old barrel is always grouted.

2.4.2 In-Line Replacements

In-line replacement activities, “involve [the] destruction of the existing pipe and installation of a new pipeline with the same or greater diameter size to the same location of the existing one” (Salem, et al, 2008). Table 2-4 lists the current methods used to replace culverts via trenchless; nevertheless, the Oregon Department of Transportation (ODOT, 2005) suggests that a new pipe can be installed in the exact same location of the existing culvert using other trenchless technologies such as pipe jacking. This and other methods are explained as follows.

2.4.2.1 Microtunneling

Based on the American Society of Civil Engineers' (ASCE's), microtunneling is "a remotely-controlled, guided pipe jacking technique that provides continuous support to the excavation face and does not require personnel entry into the tunnel" (ASCE, 2001). In this process a Microtunneling Boring Machine (MTBM) is jacked into the soil to create a space for the new culvert to be installed. Microtunneling has been used to install of new culverts under railroads; however, there is no scientific evidence to the moment of the use of microtunelling for replacement of culverts. For instance, the method is recommended by the U.S. Department of Agriculture – Forrest Service (USDA) to install new culverts but no special construction guidance about replacement via microtunneling is given. In one statement (Piehl, 2006) the USDA explains that "this method is used to install pipes of all sizes, typically in long runs that far exceeded the length of a typical USDA Forrest service Culvert." Microtunneling is a potential culvert replacement technique that pulverizes culverts depending on the pipe material using a special MTBM; but, since the use of this type of equipment is costly it might not be the method of choice for most projects.

2.4.2.2 Horizontal Auger Boring

In the Horizontal auger boring process, a horizontal hole is created by continuously excavating using a rotating cutting head attached to an auger that continuously removes the excavated soil (Stein, 2005). The soil removal principle of the horizontal auger boring process imitates the Archimedean screw water raising apparatus. The auger boring equipment is composed of three major components: the auger, the pipe encasement and a jacking unit. The encasing pipe is always made of steel; the auger rod string, with the fixed cutting head comprises the auger string (Stein, 2005). Is believed in the industry that the horizontal auger boring process is potentially able to replace culverts; however, this research was not able to find scientific evidence supporting it.

2.4.2.3 Pipe Bursting

This in-line replacement method applies force from within the existing culvert to break brittle culvert pipes, such as concrete and clay. This process forces the existing pipe segments outward into the surrounding embankment while simultaneously drawing a new pipe of the same diameter, behind the bursting head (Piehl, 2006). Replacement of small diameter culvert by larger ones might not be recommended due to the high possibility of bumping the road and fracture the pavement structure. With the exception of Corrugated Metal Pipe (CMP), pipe bursting is suitable for most culvert materials. The use of pipe bursting on a CMP culvert will cause the corrugations to bend, the pipe to buckle, bunch up and the tool to jam in the existing culvert (Piehl, 2006).

2.4.2.4 Pipe Jacking

Pipe Jacking is a trenchless method used to install prefabricated steel or concrete culverts through the ground using hydraulic jacks. The culvert is installed in segments, as each segment is jacked in, the rams of the jack are retracted and a new section of pipe is lowered down in position for the jacking cycle to begin again (ODOT, 2005).

Pipe jacking has been successfully used to install concrete culverts as explained by Thompson (2008): Nebraska Department of Roads (NDOR) worked with engineers from Rinker Materials – Concrete Pipe Division to specify a 108 in. diameter Reinforced Concrete Pipe (RPC) for jacking purposes as an alternative to constructing a box culvert. In this case, NDOR decided to jack the culvert pipe to keep the highway open to traffic during construction.

2.4.2.5 Pipe Ramming

Pipe ramming allows installations of culverts using a percusion (also called impact) tool to drive an open-ended or closed-ended steel casing. This method requires less equipment than other in-line replacement methods, which requires also a short set up times (Griffin, 2002). Pipe ramming is an efficient way of getting a new culvert in, by ramming in a larger-diameter culvert, concentrically swallowing the existing pipe while maintaining the existing location and grade of the drainage flow. Using this method, there is no concern about creating voids in the embankment because there is minimum soil displacement (Hammerhead, 2008); however, when replacing culverts voids may occur if the original culvert collapses while installing the new pipe. The method of pipe ramming is not only applied to the installation of pipelines but more recently also for pipe arching or pipe roofing (Stein, 2005).

2.5 Other Approaches

2.5.1 Pipe Roofing

Pipe roofing is a construction technique often used to aid size-up projects for tunnels below traffic roads. In this technique, steel pipes are either jacked or rammed one after the other and guided into welded-on locks (Stein, 2005) over an existing tunnel, forming a roof, onto which the ground is supported, allowing removal of soil beneath the pipe-roof. Dobashi, et al, explains that, in a tunneling expansion project in Tokyo metropolitan area, the pipe roofing method was adopted mainly to mitigate the adverse effects on the surrounding environment; however other reasons were: shallow excavation depth, location just beneath a road intersection and because important utilities were buried at various locations around the project (Dobashi, et al, 2006). Figure 2-8 illustrates a circular structure derived from the pipe roofing technique, in Germany.

Figure 2-8 Pipe Roofing Project in Germany (Tracto-Technik, 2004)

2.5.2 Special "I" Beam Ramming

As explained by a recognized underground installation company, "I" beams have been horizontally rammed in the United Kingdom (UK). In a special road improvement project, 82 "I" beams were rammed to create the roof and side wall structures of a railway underbridge. This massive tunneling project was believed to be the first of its kind in the UK. One of the first on-site solved problems encountered was the difficulty to effectively transmit the energy from the ramming machine to the "I" beams; as a solution, a special ramming plate of 3 in. (75 mm) thick was manufactured with special fixings for the plate to the "I" beam. The investigated source explains that 42 "I" beams were installed in 12 days, which met the target of 3.5 per day; the approximated total ramming distance from side to side of the embankment was 46 ft (14 m). Figure 2-9 shows the overall jobsite from one side of the embankment (Tracto-Technik, 2004).

Figure 2-9 Jobsite of the Special "I" Beam Ramming Project (Tracto-Technik, 2004)

2.6 Metal Sheet Piling

Due to the close connection between the metal sheet piling construction process and the development of the new culvert replacement tool, this method of constructing retaining walls is investigated and detailed to what pertains to the development of the new culvert replacement method.

The ASCE describes a sheet pile wall as “a row of interlocking, vertical pile segments driven to form an essentially straight wall with a plan dimension sufficiently large that its behavior may be based on a typical unit” (ASCE, 1996). In general, sheet piles are used to transmit vertical or lateral loads to soil-bearing stratum. Specifically sheet piles may be used for river control and flood defense, ports and harbors, support for pumping stations, bridge abutments, road widening or retaining walls, basements, underground parking lots, containment barriers, and other temporary work (ArcelorMittal, 2008).

2.6.1 Uses and Types of Sheet Piles

Three principal materials are mainly used for sheet piles, they are: timber, concrete and steel (Schroeder, et al, 2004). However, due to the necessity of using metal sheet piles for the new culvert replacement model, they will be further detailed.

Heavy-gauge steel is the material most commonly used for sheet piles in part due to its relative light weight, strength, long service life (ASCE, 1996), market availability and acceptability. Metal sheet piles are fabricated by either hot-rolled or cold-rolled processes and always have interlocking ends (ASCE, 1996). The hot-rolling process produces a geometrically defined interlock that is different from the one obtained using the cold-rolled process (Peurifoy, et al, 2006). The z-type piles are mostly used for retaining walls and floodwall applications where bending strengths govern the design; and when interlocking tension is the primarily consideration of the design, an arched or straight piling web should be used (ASCE, 1996). U-type piles and H-type piles are also used in construction; these typical sections are illustrated in Figure 2-10.

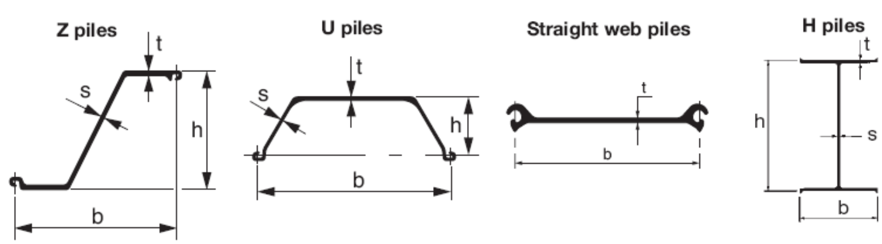


Figure 2-10 Typical Hot-Rolled Sheet Pile Sections (ArcelorMittal, 2008)

2.6.2 Cellular Sheet Pile Structures

Straight web piles are used to form cellular sheet pile structures in marine environments, they serve as cofferdams, bulkheads, mooring dolphins, and lock guide walls (Wissmann, et al, 2003). The concept of cellular sheet pile structures considers a ring wall, that is constructed progressively by setting driving interlocking sheet piles to form a closed cell. A cellular structure can be as simple as an independent circular cell, or it could be a series of interconnected cells. The cells are usually constructed using an even number of sheet piles (Hammersteel, 2009). The cellular sheet pile formation performs best when the general horizontal cross section of the cell geometry is maintained within the tolerances; the piles are stretched in tension by the fill its inside with earth, thus, generating friction of the interlocks (Ratay, 1996). An illustration of a circular cellular sheet pile structure is shown in Figure 2-11.

Figure 2-11 Circular Cellular Sheet Pile Project (ArcelorMittal, 2008)

As explained by the U.S. Army Corps of Engineers there are three types of cellular structures: circular cells, diaphragm cells, and cloverleaf cells. The circular cells consist of a series of complete circular cells connected by shorter arcs. The diaphragm cells are comprised of a series of circular arcs connected by 120-degree intersection pieces or crosswalls.

Cloverleaf cells consist of four arc walls connected to each other in each quadrant (USACE, 1989). Figure 2-12 shows the layouts for circular cells and diaphragm cell configurations; for the purpose of this thesis only circular cells will be employed in the development of the new culvert replacement method.

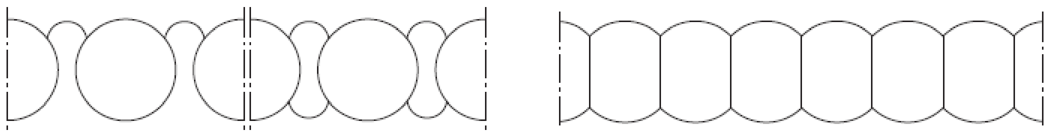


Figure 2-12 Circular Cells and Diaphragm Cells Configurations (ArcelorMittal, 2008)

Straight web piles used for cellular sheet pile structures have low flexural stiffness, which means that care must be taken when handling them. If deformation occurs when handling, the interlocking thread may be difficult to accomplish. Straight web piles are rolled by most suppliers in lengths of up to 100 ft (30.5 m) and in nominal widths of 19.7 in (500 mm); however, larger lengths can be obtained upon request to the supplier. “Most steel sheet piles are supplied in standard American Society for Testing and Materials (ASTM) 328 grade steel, but high-strength low-allow grades ASTM A572 and ASTM A690 are available for use where large loads must be supported or where corrosion is a concern.” (Peurifoy, et al, 2006). Interlocking strengths of straight web piles can go up to 24 kips/in (4,200 kN/m) with interlocking swings of more than 10 degrees; higher interlock strengths are available, however with reduced swing. Typical dimensions and interlocking swings of straight web piles are illustrated in Figure 2-13.

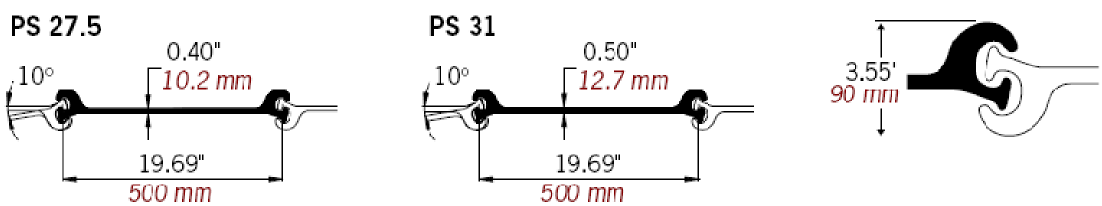


Figure 2-13 Straight Web Pile Common Dimensions (Chaparral, 2006)

2.6.3 Pile Hammers

As explain by the ASCE, steam, air, and diesel are the most common types of hammers used to drive metal sheet piles. These hammers may transmit the necessary energy to the piles by single-action, double-action, differential-action, or vibratory. Vibratory hammers may perform faster than impact hammers; however, when the penetration rate is 1 ft (0.3 m) per minute or less, the use of impact hammers should be employed. On the other hand, the use of impact hammers on hard soils may sometimes melt the interlocking joints (ASCE, 1996). Peurifoy, et al, explains that metal sheet piles are usually driven with the use of a vibratory hammer and using a guide frame or template. The guide frame should be at least half the length of the sheet piles to help maintain verticalness and avoid bending. To thread the metal sheet piles automatically, threading devices can be employed (Peurifoy, 2006).

2.7 Cost Estimation and Cost Benefit Analysis Concepts

A cost estimation for the proposed culvert replacement method is a main assignment for this investigation in order to prove economic feasibility; therefore, the cost estimation concepts and procedures are investigated. In the same manner, the cost-benefit analysis theories are explained in this section for future research projects.

2.7.1 General Facts and Types of Estimates

As Peurifoy and Oberlender explain, estimating is not an exact science and its purpose is to forecast the costs required to complete a project in accordance with the plans and specifications. The estimation of material costs is a relatively simple task when compared to the estimation of labor and equipment. The estimation of labor and equipment requires the determination of productivity rates, which may change from one job to another. Therefore, the estimator is often required to provide production rates, crew sizes, equipment spreads, and estimated time required to perform individual work items. The combination of this information allows the determination of the approximated cost of a project.

For some authors (Peurifoy and Oberlender, 2002) there are two types of estimates: approximate estimates and detailed estimates; for other authors (Holm, et al, 2005) there are three major types of cost estimates: conceptual cost estimates, semi-detailed cost estimates and detailed cost estimates. For the purpose of this thesis, the author will use the approximate and detailed estimates approach, to eliminate the “semi-detailed” term ambiguity.

An approximated estimate may be obtained by reducing a building or project to square feet of area, cubic feet of volume or simply feet of installation to later multiply the number of units by the cost per unit. A detailed estimate is prepared by determining the costs of materials, labor, equipment, subcontract work, overhead, and profit. Previous to a detail estimate, a quantity takeoff should be performed by reviewing plans and specifications. In this process the amount of work required to build the project is quantified (Peurifoy and Oberlender, 2002).

2.7.2 Cost-Benefit Analysis Types

As Boardman, et al, explains, the general purpose of cost-benefit analysis is to help in decision making processes and specifically it is design to facilitate efficient allocation of society’s resources. The cost-benefit analysis is divided into two major types: *ex ante* and *ex post*. *Ex ante* analyzes the project before is being built and when is being only considered. *Ex post* is performed when the project is finished. There are other types of cost-benefit analysis such as the *in media res*, which analyzes projects while they are being built. Another type of cost-benefit analysis is the study and comparison of two of the previous explained types. This last type of cost-benefit analysis is more useful for learning about the efficacy of cost-benefit analysis as a decision-making tool (Boardman, et al, 2006). This thesis addresses the attention to *ex ante* analysis because it helps to select the best alternative between “go” or “no-go” decisions; however, it may not give accurate predictions.

2.8 Findings from the Literature Search

An analysis of the written information of the previous sections set preliminary conclusions regarding trenchless replacement of culverts, they are listed as follows.

- It is important to acknowledge that the number of culverts in need of replacement is considerably large. Nationally recognized entities and other research reports have calculated an approximate number of culverts in peril.
- While investigating the culvert replacement options, not many were found. There are options that have been proved to replace culverts via trenchless are: pipe jacking, pipe bursting and pipe ramming; other possible trenchless alternatives are: horizontal auger boring and microtunneling.
- Not many scientific studies were found about the trenchless replacement alternatives cited above. Therefore, they have not been deeply researched.
- Not all the culverts are economically or physically suitable for replacement via trenchless. Some culverts are located in areas with difficult access or without a wide right-of-way.
- Certain specific conditions must be encountered or investigated in order to implement trenchless technology on culvert replacement, therefore, is site specific.

2.9 Chapter Summary

A comprehensive literature review for culverts and specifically for culvert replacement via trenchless is covered in the previous sections. The chapter begins with a general definition of culverts and its components. It continues with a clear definition of various engineering and non-engineering principles pertained to culvert design. A description of underperforming culverts and the factors influencing them is listed and briefly analyzed; the list of factors can be grouped in durability, structural, environmental, geotechnical and design factors. The chapter continues investigating the current trenchless technologies capable of replacing culverts; they are divided into “in-line replacement,” and “liners.” This research work focuses more on “in-line replacement” technologies; some of the technologies found in this category are: pipe bursting, microtunneling, horizontal auger boring, pipe jacking, and pipe ramming can be encountered. Other tunneling procedures such as: pipe roofing, and “I” beam ramming, are studied as a background to the development of the new culvert replacement tool. In conjunction with these tunneling procedures, the metal sheet piling construction procedures and more specifically the cellular sheet piling process is investigated. Lastly, a general introduction to cost estimation and cost benefit analysis finishes the chapter.

CHAPTER 3

CONCEPTUAL DESIGN AND CONSTRUCTION METHODS

3.1 Introduction

After investigating the fundamentals of culvert and trenchless technologies applied to culvert renewal, the researcher idealized a new method, potentially able to replace culverts. In November of 2008, the author conceptually developed the new method by combining other existing construction processes: pipe ramming, pipe jacking, cellular sheet piling and pipe roofing. With technical advice of Dr. Mohammad Najafi, the herein detailed tool and its capabilities were presented to the civil engineering community at national and international conferences (ASCE Pipelines 2009 Conference in San Diego, California and ASCE International Pipelines and Trenchless Technology Conference in Shanghai, China). Although similar technologies like pipe bursting had been adapted to serve as in-line replacement alternatives for culverts, most have been rarely used or proven for culvert replacement. Therefore, it must be imperative to develop new technology due to the urgency and the large amount of work that the culvert replacement strategy will need.

3.2 General Idealization of the Model

Some of the construction techniques explained in the previous chapter are combined here to generate a new tool. The process is best described as a closed pipe roofing project using metal sheet piles, which are driven by ramming forces. The main purpose of the model is to enable culvert upsizing by ramming a new and bigger cross section formed by metal sheet piles over the external surface of the host culvert (Calderon and Najafi, 2009). Figure 3-1 shows the same Figure 2-11 but tilted to illustrate the main idealization of the arrangement of the metal sheet piles near a culvert on the right of the image; it is the most probable approximation of how it will look like in a real culvert replacement project.

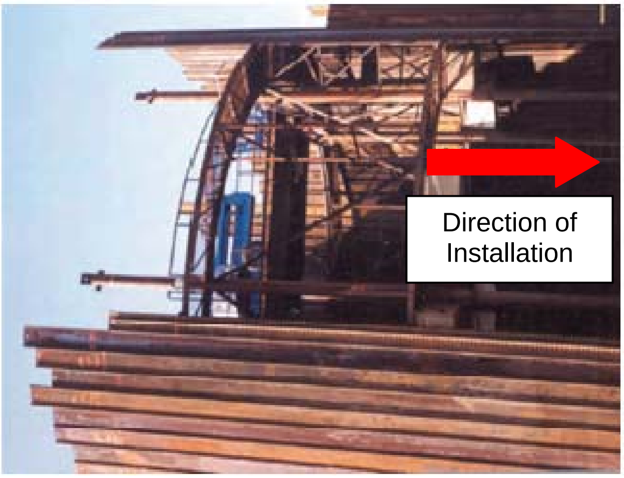


Figure 3-1 Metal Sheet Piles Tilted Horizontally (ArcelorMittal, 2008)

Based on the previous assumptions, a rendering of the model is illustrated in Figure 3-2; note that the rendering shows a longitudinal section of the horizontal sheet piling process in a hypothetical installation over a corrugated metal culvert, also note that the culvert runs across a road embankment. This proposed construction method is targeted to replace culverts of various materials in specific locations as explained in the next section.

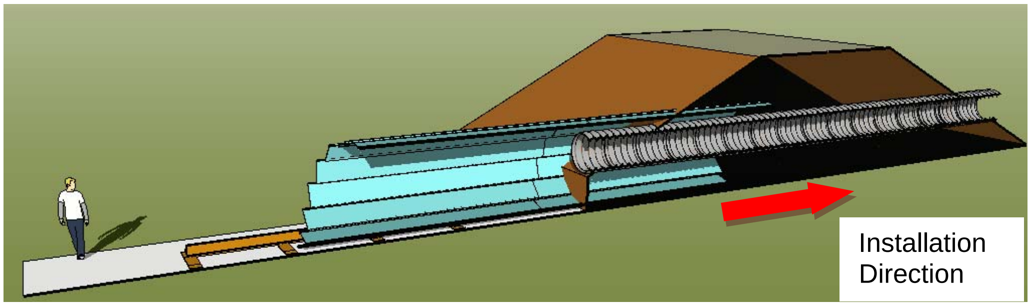


Figure 3-2 Render of the Horizontal Sheet Piling Method

3.3 Method Applicability

As conceived, this new method aims to expand the current alternatives to replace a culvert via trenchless in highly congested two way roads and railroads; nevertheless, the process is not suitable yet to replace culverts in highways or when the depth of cover is shallow. The proposed process is specifically targeted to: replace, install, upsize, reduce, and diminish as explained as follows.

Replacement of different culvert materials, sizes and shapes is a must for the horizontal sheet piling process. This first application gives a set of important advantages against similar processes such as pipe ramming. However one of the drawbacks is the limitation of length; until it became proven by laboratory tests or real life tests, the horizontal sheet piling process will be limited to lengths of up to 100 ft (30.5 m).

An installation of a totally new culvert in road embankment is also possible with the proposed methodology; however, because of the unknown condition of the embankment, the researcher suggests site specific geotechnical reports to avoid boulders in the embankment as much as possible.

Upsize-ability is one of the key features of the new process; however, it is dependent on the depth of cover between the culvert crown and the road surface. Using the horizontal sheet piling process, a culvert can be upsized to an almost unlimited ratio.

Reduction of construction or installation costs, are expected for this new development, in part due to the possibility of using sheet piles available in the market from different manufacturers. However, this statement is subject to the analysis on Chapter 4 and a comparison against other similar trenchless techniques.

Lastly the invention and later use of the metal sheet piling process will help to diminish the rate of collapses and sudden catastrophes caused by culverts worldwide and in the U.S. road network. With this invention, a city will have another tool to choose that may be more cost effective.

3.4 Conceptual Design

The model resembles a ramming process but with the pipe divided in longitudinal and interlocked segments. The method provides encasement for the host culvert, allowing its later removal. Cellular sheet piling uses interlocking joints which in this method provide structural support for the encasement. Once the theory reviewed was done, the invention was modeled in a three dimensional computer aid design program to better understand its components and major characteristics.

3.4.1 General Components of the Model

As explained before, the model is a combination of different construction techniques; therefore, the components of the new invention should have the same or similar components of the combined techniques. Although Figure 3-3 and Figure 3-4 show some of the components of the horizontal sheet piling process, the reader should be aware of other components as explained in this section.

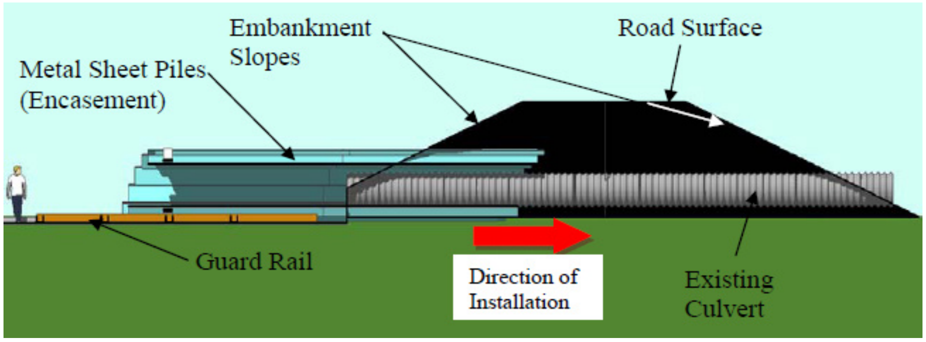


Figure 3-3 Horizontal Sheet Piling Lateral View

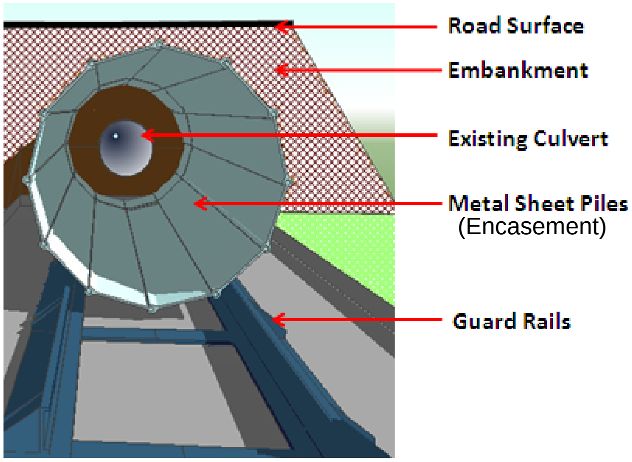


Figure 3-4 Horizontal Sheet Piling Frontal View

One of the most important components of the model are the sheet piles. The metal sheet piles should be designed to carry and transmit compression loads. Another important element is a template, which must be used to keep the alignment of the metal sheet piles, and should be similar to the ones used for cellular sheet piling. A guard rail is also an important element of the model because it provides alignment and stability to the encasement. Other important components of the model include a pneumatic rammer and a special ramming adapter to transfer the force between the rammer and the sheet piles.

3.4.2 Metal Sheet Piles

Based on best market availability, the author suggests the use of steel-sheet piles with the highest swing and interlock strength and of the following dimensions and characteristics. Straight web piles and specifically the interlocking elements are manufactured to withstand tension. Even though it is anticipated that the interlocking elements will have to withstand compression forces, the researcher suggests the use of the maximum interlocking strength for tension available for the horizontal sheet piling process. The average maximum interlocking strength among manufacturers is 24 kips/in (4,200 kN/m). It is important to note that interlocking of sheet piles from different manufacturers is usually impossible. Figure 3-5 shows a cross section of a generic sheet metal sheet pile with the average market dimensions recommended by the author. The selected metal sheet piles should swing at least 10 degrees from one to the next one.

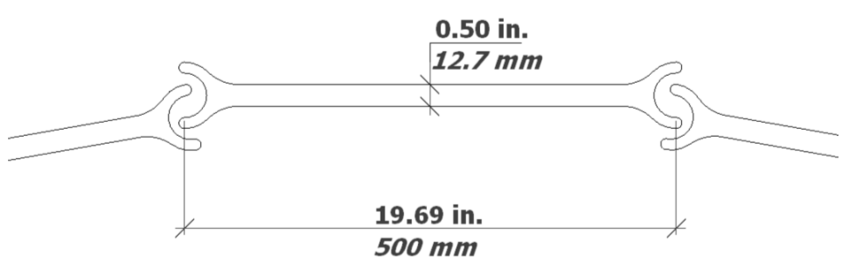


Figure 3-5 Generic Metal Sheet Pile Dimensions

If it is necessary to have more swing capacity sheet pile manufacturers often supply pre-bent piles as shown in Figure 3-6.

Figure 3-6 Bent Piles (ArcelorMittal, 2008)

3.4.3 Templates

A template should be used for every horizontal sheet piling operation to help preserve the alignment of the installation. The template should be designed and constructed using steel elements, and should be similar to the ones used for cellular sheet piling projects. In cellular sheet piling, the templates are first secured to the ground and then the piles are driven; however, for the horizontal sheet piling process, the template can be either secured to the road embankment or not. The diameter of the template structure is limited by the diameter of the sheet piles to be driven; therefore, specific templates must be constructed depending on each project. Figure 3-7 shows a typical template layout for a horizontal sheet piling process, the structure is a modified version of a cellular sheet piling template structure (TESPA, 1995).

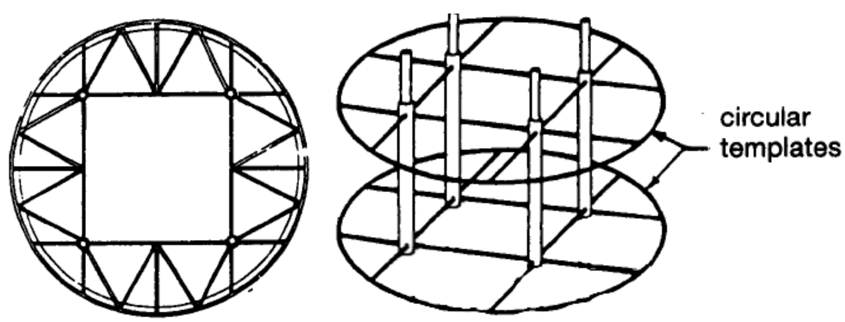


Figure 3-7 Typical Template Structure

3.4.4 Guard Rails

Guard rails are elements that transfer the weight of the metal sheet piles to a concrete mat while helping preserve the alignment of the installation. Figure 3-8 shows four possible guard rail settings; the guard rail configuration should always be supported on a solid reinforced concrete mat.

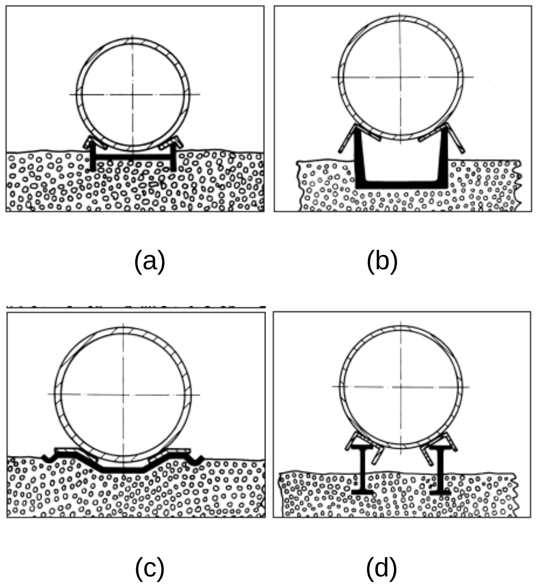


Figure 3-8 Various Encasement Support Systems (TT Technologies, 2002)
(a) Alignment on I-Beam (b) Alignment on C-Channel (c) Alignment on Sheet Pile
(d) Alignment on Two I-Beams

For the purpose of this study the researcher considers that Figure 3-8(c) is the most suitable arrange for the guard rail, because it may be more cost effective. The use of sheet piles for the guard rails and for the encasement may lead to discounts by the sheet pile manufacturer.

3.4.5 Cone Adapter

A specially designed cone adapter is used in the horizontal sheet piling process. The adapter should be similar to the ones used for soil removal in pipe ramming operations; however, simple modifications should be manufactured in order to better transmit the ramming forces to the sheet piles or encasement. Figure 3-9, shows a model of the proposed cone adapter.

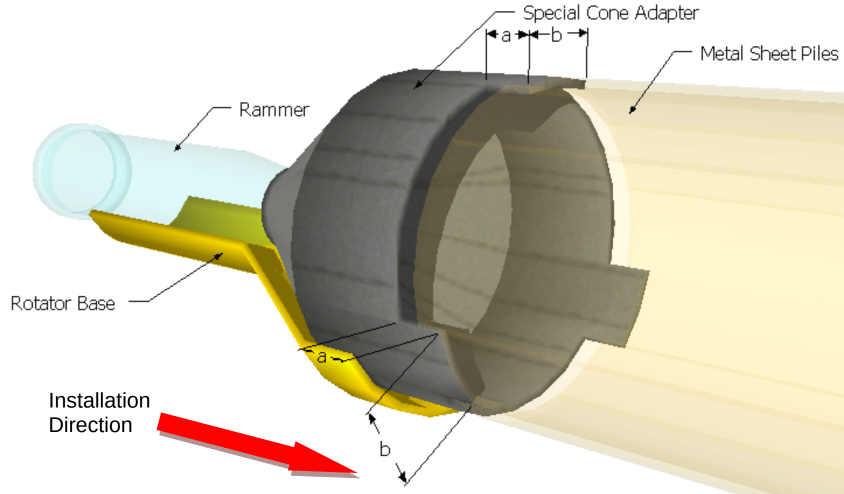


Figure 3-9 Special Cone Adapter Model

As shown in Figure 3-9 the cone adapter should be manufactured with special contact elements that may contact the sheet piles one by one, in pairs or triplets. It is recommended by steel manufacturers that straight web piles be driven in pairs to reduce jams in the interlocks and to drive energy to concentrated mass of interlocks instead of a thin web (TESPA, 1995).

3.4.6 Pneumatic Rammer

Hammering equipment used for pipe ramming operations should also be used for the metal sheet piling process. The hammer must be attached to the cone adapter and rotate both at the same time each pile or set of piles are driven a set distance. As well as any pipe ramming process, the designer should select the most appropriate hammer for the horizontal sheet piling process; carefully selecting a powerful tool that will drive the piles without destructing or bending the metal sheet piles. For instance, Peurifoy, et al, (2006) explains that for a pile driving operation using double acting hammers or rapid blow hammers, it is possible to attain a desired amount of energy per blow because of the piston compression both when rising and falling. This principle may also apply to ramming equipment in pipe ramming operations, most manufacturers supply tables (Hammerhead, 2009) with recommended equipment depending on the size of the installation.

3.5 Installation Process

This section explains all the processes needed to install a new culvert using the horizontal sheet piling from the selection of the embankment side to the removal of the damaged culvert. The means and methods to accomplish the following tasks will not be the main subject of the discussion, because they are usually established by the subcontractor. Detailed activities such as mobilization or demobilization will be explained in chapter 4 due to the general understanding of the terms.

3.5.1 Embankment Slope Selection

The two slopes of a road embankment in a culvert structure differ one to another in all cases. Differences in embankment sides may include: soil properties, type and condition of the vegetation, adjacent structures, topography, right-of-way limitations, flow direction, slope of the existing culvert, or the like. When such differences are evident and may impact the total cost of a replacement project, a careful selection of the best side should be made. The selected side will serve as the entry pit for the installation of the horizontal sheet piling process.

As a general recommendation, an engineer should select the side that provides better load bearing capacity, is not affected by adjacent structures and is upstream. Figure 3-10 shows some of the factors that may be determinant when selecting one of the road embankments for culvert replacements.

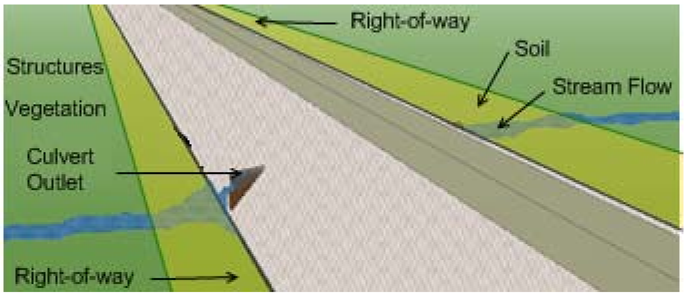


Figure 3-10 Embankment Slope Selection

3.5.2 Bypassing

Bypassing is almost always necessary in any trenchless technology; the herein explained methodology is not the exception when replacing culverts in wet seasons. When the stream cannot be redirected to an adjacent sewer, the stream must be dam upstream and a pump with adequate capacity should be used to conduct the water from one side to another side of the embankment as shown in Figure 3-11. By doing this, the work pit area adjacent to the selected embankment side is dewatered and dried as much as possible.

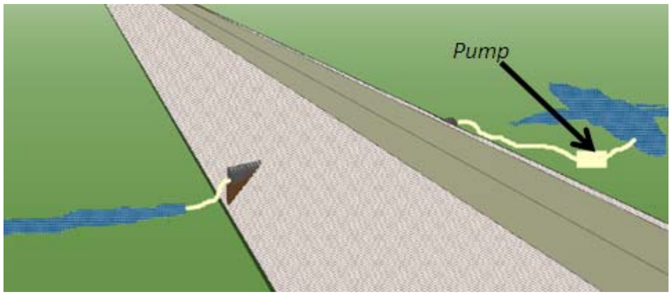


Figure 3-11 Bypassing

3.5.3 Work Pit Construction

A reinforced concrete mat floor must be built to assure a distributed load transfer to ground, stability of the sheet pile arrangement, and alignment of the installation. The author recommends one and a half times the diameter of the sheet pile arrangement for the width of the mat. The thickness of the concrete mat should be designed following the general standards and codes for reinforced concrete design. Instead of using a thick reinforced concrete mat, depending on the soil conditions and to make the model more cost effective, a contractor can also use a well compacted layer of soil topped with a light layer of concrete. Figure 3-12 shows a general layout of the reinforced concrete mat and the surroundings of a work pit.

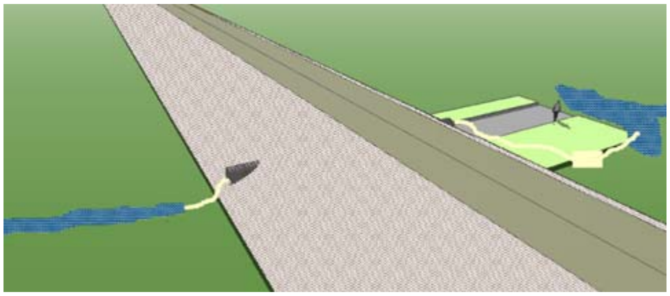


Figure 3-12 Work Pit Construction

3.5.4 Guard Rail Installation

As explained before, guard rails aid to maintain the alignment of the replacement process. They should be embed and attached to the concrete mat and as close as possible to the original culvert. Figure 3-13 shows a general layout of where the guard rails should be placed.

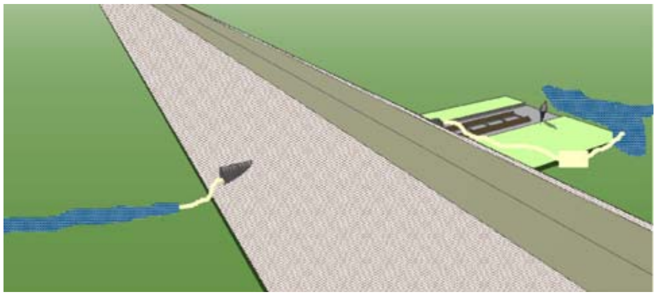


Figure 3-13 Guard Rail Installation

3.5.5 Assembly of Horizontal Sheet Piles

The assembly of the metal sheet piles is probably the most labor intensive activity of the whole installation process. To accomplish it, the author suggest the use of a crane to hold metal sheet piles in a vertical position one interlocked to another and attached to the template in a circular shape creating a pipe. After all the piles are interlocked and attached to the template, the crane is used to rotate the created pipe to a horizontal position as shown in Figure 3-14. In this step, special sheet piling anti-leak epoxies can be applied to the interlocks.

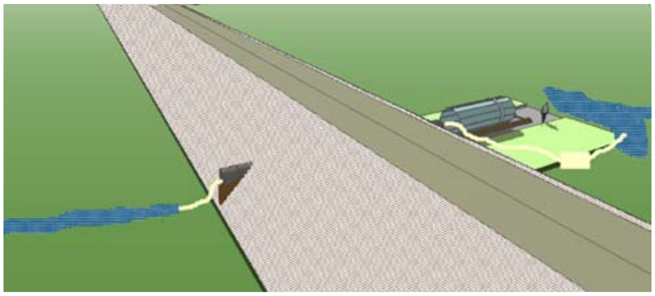


Figure 3-14 Assembly of Horizontal Sheet Piles

3.5.6 Insertion of Horizontal Sheet Piles

The insertion process is another demanding step; however, not as labor intensive as the assembly of the metal sheet piles. The first task should include the disconnection and the reconnection of the water pump hose to allow the in-line location of the metal sheet arrangement, the cone adapter, and the cone adapter-rotator, as shown in Figure 3-15.

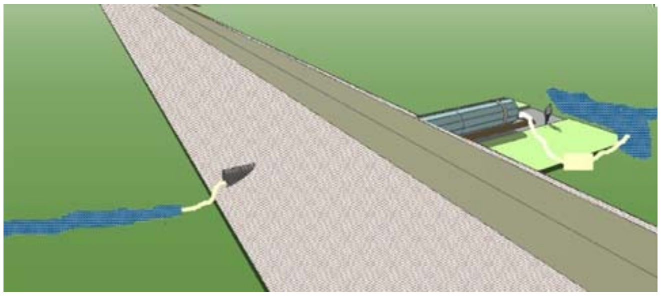


Figure 3-15 Insertion of Horizontal Sheet Piles

The generic action of the special cone adapter is to insert the sheet piles one by one, three at a time or in groups two piles into the embankment and surrounding the host culvert. The special cone adapter must drive the metal sheet piles a set and relatively small distance to minimize the bending of the metal sheet piles inside the embankment. Once a set of piles have been driven, the cone adapter is rotated to allow the driving of adjacent metal sheet piles. These tasks are continuously repeated until all the metal sheet piles cross the entire embankment. The sequence of the cyclic activities that contributes to the insertion process is shown in the diagram of Figure 3-16; the result of one round of the installation process is illustrated in Figure 3-17.

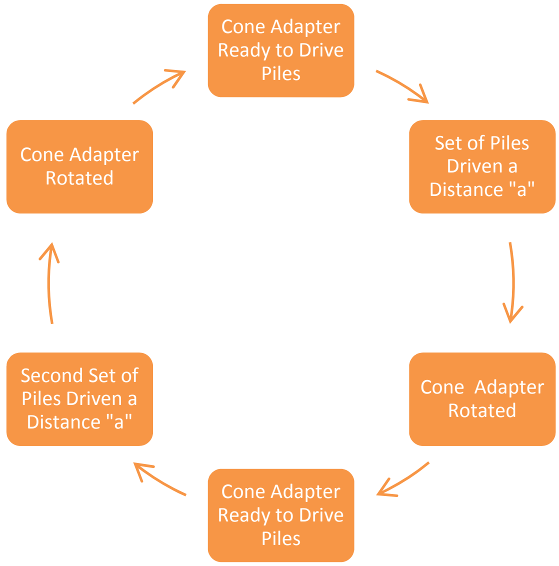


Figure 3-16 Insertion Process Activity Cycle Diagram

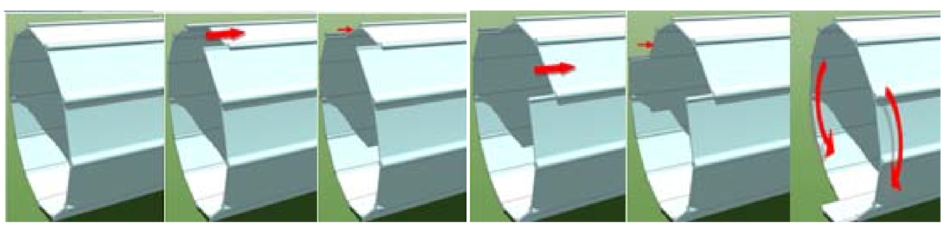


Figure 3-17 Horizontal Sheet Piling Insertion Process

The insertion process concludes when by following these cyclic activities the arrange of piles get to the other side of the embankment as seen in Figure 3-18; this creates a sleeve that encases the deteriorated host culvert.

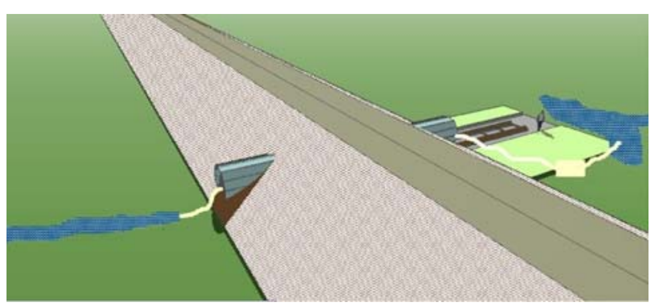


Figure 3-18 New Culvert Inserted

3.5.7 Removal of the Original Culvert

Once the culvert has been encased; the encasement can withstand and transfer the loads, giving the possibility to remove the deteriorated culvert and therefore upsize its diameter. Removal of the deteriorated culvert may require the use of demolition tools such as pneumatic chisels. Cities may opt to leave the deteriorated culvert in place; however, this may be recommended only when the deteriorated culvert only has structural problems not when it has flow capacity problems.

3.5.8 Cleaning of Horizontal Sheet Piles Inner Surface

Soil or dirt can remain attached to the sheet pile encasement after removing the deteriorated culvert. In order to better apply a protective coating to the new culvert, these contaminating elements should be removed. This research recommends water jetting to perform this cleaning activity.

3.5.9 Protective Coating or Liner Installation

If the metal sheet piles are installed with an anti-corrosive layer of paint, the friction of the soil with the metal sheet elements may scratch the paint and loose it allowing water to corrode the metal elements. As an alternative, the author suggests the use of a protective coating in the inner side of the culvert after the metal sheet piles have been installed. The selected protective material should be applied following the supplier installation procedures and along the entire circumference of the culvert shape.

3.6 Equipment and Materials

By studying similar approaches, the author anticipates the use of the following equipment and materials for the entire installation process. The following section is limited to the researcher knowledge to the moment of the publication of the current thesis, its purpose is to identify where equipment and material costs may be employed.

The use of backhoes, compactors, cranes, templates, pneumatic rammers, earth moving trucks and on-site personnel trucks are the anticipated list of equipment to be used in a horizontal sheet piling operation. Materials such as metal sheet piles, anti-corrosive coatings, anti-leakage composites, concrete and rebar might be generally specified as well. For better final results, the author suggests the use of high-quality materials along with quality control inspections.

3.7 Model Advantages and Limitations

The following section brings the reader's attention to the capabilities and weaknesses of the conceptual development. Some of the advantages and disadvantages shown hereinafter are generic to all the trenchless technologies; however, there are also some specific to the new model.

3.7.1 Limitations

- The new methodology may not be suitable for wide highways
- High friction of the interlocks may damage or jam metal sheet piles during the installation
- Filtration of water through the interlocks may bring a corrosion friendly environment to the steel
- The demolition of the damaged culvert could be both difficult and hazardous.
- As well as other similar technologies, bypassing the stream flow is a major drawback; however, to avoid this problem the installation of a new culvert with this technique could be performed in dry seasons
- For the general public, the need for a protective lining material could mean an extra cost to the project

3.7.2 Advantages

- Upsize-ability, that is only dependent on the available space between the underperforming culvert and the structure of the road
- Different types of cross section shapes can be configured

- As with other trenchless technologies, the new methodology brings less disruption of the traffic and therefore less social costs
- Replacement of culverts can be accomplished even with stream flow
- Market availability of the metal sheet piles means price competition and therefore cost savings
- The metal sheet piles encasement has structural behavior
- When replacing large diameter culverts using pipe ramming, there is no need to transport large size steel pipes

3.8 Chapter Summary

In this chapter the researcher idealized a new method that is potentially able to replace culverts. The proposed model was conceived by combining pipe ramming, pipe jacking, cellular sheet piling and pipe roofing altogether. In essence, the new methodology resembles a ramming process but with the pipe divided in longitudinal and interlocked segments which provide encasement for the host culvert, allowing its later removal. The metal sheet piles are one of the major components of the new invention, which are formulated and described in this chapter following some characteristics of other construction processes. The steps to install these components into the road embankment and around the underperforming culvert give the reader a broader view of how the new idea will be materialized. Each major step of the process is detailed along with illustrations. A general recommendation on equipment and materials gives further detail. Lastly the chapter closes studying the advantages and limitations of the new method, which in general terms gives the reader a view of the intended target for the model.

CHAPTER 4

THEORETICAL COST ESTIMATION ANALYSIS

4.1 Introduction

As explained in previous sections, one of the fundamental objectives of this thesis is the development of a cost estimation analysis to demonstrate the economic feasibility for the process. The cost analysis for the new methodology is developed only in a theoretical framework because the methodology has not been used yet in a real project. The cost forecast is important for any new invention because it evaluates the economic feasibility and helps on the decision of whether to proceed investigating it or not. The author believes that at the conclusion of this chapter, the reader will have a good indication of the feasibility of the process. In the following sections the author investigates the theoretical cost of an imaginary culvert replacement project using the newly developed technology. Length, size, soil properties and other parameters are assumed to formulate a case and perform the cost analysis. Based on a feasibility survey of the methodology and the knowledge received from industry experts in various national and international conferences, the author is able to define the expected number of labor and equipment needed. The investigator also prepared technical drawings of a made-up culvert replacement project, which will aid in the quantity takeoff. The herein explained cost estimate process is described in the literature as a detailed estimate; however, due to the theoretical nature of the development, an elevated contingency percentage is employed.

4.2 Culvert Replacement Project Sketch and Generics

In order to generate material quantities for the made-up project, the researcher created drawings of a culvert replacement project based on his general expertise in civil engineering. Due to the installation limitation of 100 ft (30.5 m), a two-way road with one single line in each direction was selected; however, other crossings can be performed such as in railroads or levees. The author believes that the created project is the most probable situation in which the new culvert replacement method may become useful. Figure 4-1 shows a sketch of the theoretical culvert replacement project, more detailed drawings showing dimensions are shown in Appendix A.

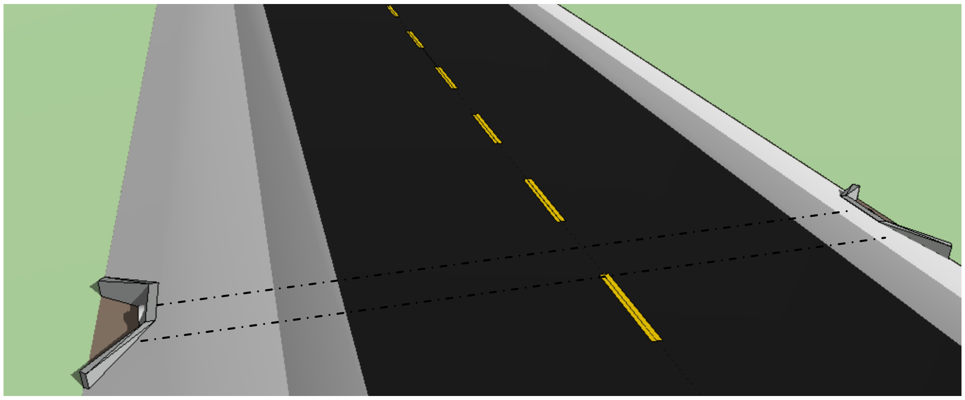


Figure 4-1 Drawing of the Theoretical Project

4.3 Material Quantity Takeoff

Even though the Construction Specifications Institute (CSI) – MasterFormat™ is used for building construction, this research used this standard format to attain more items; thus creating a broader list of cost items. Using the CSI format, the recommended construction cost items were classified. The CSI format lists titles and section numbers for organizing data regarding construction requirements, products, and activities. It is a useful standardization and communication tool among the owners, engineers, contractors, manufacturers and facility managers (CSI, 2004). The list of divisions comprehending the CSI-MasterFormat™ is shown in Table 4-1. In this chapter each construction cost item is numbered following the CSI format which consists of a Division, a Phase, and an Item number. For instance the number for grass seeding in the material quantity takeoff is 32 92 19; which accounts for Division 32 "Exterior Improvements," Phase 92 "Turf and Grasses," and Item 19 "Seeding."

Table 4-1 CSI-MasterFormat™ Divisions

Division	Description	Division	Description
00	Procurement and Contracting Requirements	26	Electrical
01	General Requirements	27	Communications
02	Existing Conditions	28	Electronic safety and security
03	Concrete	29	*Reserved*
04	Masonry	30	*Reserved*
05	Metals	31	Earthwork
06	Wood, Plastics, and Composites	32	Exterior Improvements
07	Thermal and Moisture Protection	33	Utilities
08	Openings	34	Transportation
09	Finishes	35	Waterway and Marine Construction
10	Specialties	36	*Reserved*
11	Equipment	37	*Reserved*
12	Furnishings	38	*Reserved*
13	Special Construction	39	*Reserved*
14	Conveying Equipment	40	Process Integration
15	Mechanical	41	Material Processing and Handling Equipment
16	Electrical	42	Process Heating, Cooling, and Drying Equipment
17	*Reserved*	43	Process Gas and Liquid Handling, Purification and Storage Equipment
18	*Reserved*	44	Pollution Control Equipment
19	*Reserved*	45	Industry-Specific Manufacturing Equipment
20	*Reserved*	46	*Reserved*
21	Fire Suppression	47	*Reserved*
22	Plumbing	48	Electrical Power Generation
23	Heating Ventilating and Air Conditioning	49	*Reserved*
24	Reserved	50	*Reserved*
25	Integrated Automation		

As explained before, the quantities of materials are taken-off from the drawings in Appendix A and other computer aids. In this step, the quantity takeoff precision is crucial to the success of the estimate; the estimate will not be reliable if a mistake is done in the quantity takeoff process, no matter how accurate the unit prices are (RSMeans, 2005). Table 4-2 shows a summary of the quantities of materials using the CSI MasterFormat™ and RSMeans organization numbers; detailed quantity takeoff tables are pressented in Appendix C.

Table 4-2 Summary of Material Quantities

Division	Phase	Phase	Item	Description	Unit	Quantity
02	41	19.23	3000	Rubbish handling, loading & trucking, including 2 mile haul, chute loaded	C.Y.	1.56
03	05	05.10	0050	Selective concrete demolition, break up into small pieces, minimum reinforcing	C.Y.	1.56
05	01	10.51	6215	Cleaning of structural metal framing, pressure washing	S.F.	1772.80
05	05	21.10	0100	Hand burning, incl. preparation, torch cutting and grinding, steel to 1/2 in. thick	L.F.	250
09	97	13.23	6940	Exterior steel coatings, two part, epoxy spray	S.F.	1772.80
31	41	16.10	0900	Sheet piling, 38 psf, left in place	Ton	29.49
31	41	16.10	2700	High strength pilling, 50,000 psi	Ton	29.49
32	92	19.13	0800	Grass seed hand push spreader, 4.5 lbs. per M.S.F.	M.S.F.	1.38

4.4 Recommended Equipment and Personnel

In this section, the author discusses the equipment and labor needed in a typical culvert replacement project using the proposed methodology. By comparing the construction cost databases (RSMeans, 2009) and the answers to the survey (Appendix B) the author is able to recommend the most probable list of personnel needed; the list is shown in Table 4-3.

Table 4-3 Recommended Personnel

Description	Quantity
Field Engineer	1
Project Manager	1
Laborers	6
Labor Foreman	1
Welder Foreman	1
Skilled Metal Workers	2
Pipe Ramming Operator	2
Equipment Oiler	1
Truck Drivers	2
Structural Steel Painters	2
Surveyor	1
Surveying Instrument man	1
Rodman/Chainman	1

The list of recommended equipment is also compiled by combining the results of the survey (Appendix B) and the results of the selection of items from the construction cost databases. While some equipment was found easily from either source, such as dozers or excavators; there was other type of equipment such as the pneumatic pipe ramming tool that was selected by the researcher from manufacturer's literature. As explained in section 3.4.6, manufactures often supply tables with recommended pipe ramming equipment depending on the diameter of the installation. Following a pipe ramming brochure (Hammerhead, 2009) and with an installation diameter of 6 ft (1.83 m) or 72 in. (1829 mm), a ramming tool of 9,831 lb (4,459 kg) of weight should be employed; however, due to the reduction of area of contact created by the new methodology a pipe ramming tool with less capacity can also be employed. In this case, the researcher selected a ramming tool of 12 in. (304.8 mm) in diameter and 1,568 lb (711 kg). The list of recommended equipment is shown in Table 4-4.

Table 4-4 Recommended Equipment

Description	Quantity
Excavator 1 C.Y. capacity	1
Dozer, crawler, diesel 200 H.P.	1

Table 4.4 – *Continued*

Description	Quantity
Air compressor 600 CFM	1
Air compressor 250 CFM	1
20 in. (508 mm) Diameter ramming tool	1
Lowbed trailer	2
Pickup truck	2
Acetylene cutting torch	1
Laser level	1
Dump truck 16 ton, 12 C.Y.	1
Concrete breakers	2

4.5 Pipe Ramming Rental Cost Interview

In order to determine the most approximate rental cost for the pipe ramming equipment, the researcher telephonically interviewed a representative from a well recognized manufacturer and renter company (Hammerhead trenchless equipment). In the conversation, the representative was briefly introduced to the topic of this research and its scope. The contact information of this representative will not be displayed; Mr. Jeff Gabriels initials will appear in the answer line. In order to obtain more information about this resource, please contact the author of this thesis. In this section, the interview questions and its answers are listed as follows.

i. How much is the rent of a 12 in. (304.8) diameter pipe ramming tool?

JG: It depends on the project conditions such as length of installation and diameter; however, rental costs range from $5,000 to $15,000 per month.

ii. Does the rental price include the guard rails?

JG: No, materials such as the pipe or the rails are provided to the contractor from other sources.

iii. Does the rental include any labor personnel or technicians?

JG: No, that is contractor's responsibility.

iv. Does the air compressor come with the rental price for the tool?

JG: No, we only supply the ramming tool, nothing else.

Based on the results of this interview, the researcher is able to target a cost estimate for the pipe ramming tool rental and other necessary elements. It is also important to acknowledge that the interviewed representative was aware of the theoretical project location.

4.6 Direct Costs Estimate

4.6.1 Contingency

As recommended from various sources (RSMeans, 2009) (Peurifoy and Oberlender, 2002), a contingency allowance should be included in the estimate. A common contingency allowance percentage for conceptual stage projects is 20%; due to the special nature of the new technology herein explored, the researcher believes that a 20% contingency over the subtotal estimated cost may mitigate the risks of presenting a low cost estimate.

4.6.2 Computation of the Bare Cost Estimate

The cost estimate for the present experiment is calculated and organized using a spreadsheet software application. A list of the recommended items is extracted from construction cost databases (RSMeans, 2009); costs and quantities are computed to obtain the cost of each item. The costs of each item are added to in each division; afterwards the cost for each division is added to generate the total direct costs for the project. Table 4-5 shows a division-wise summary of the cost estimate. A detailed spreadsheet report of the cost estimation is presented in Appendix C.

Table 4-5 Cost Estimate Summary

Division	Description	Amount	Percentage of Total (Amount*0.816/Total)
01	General Requirements	$ 23,119.03	25.59
02	Existing Conditions	$ 54.44	0.06
03	Concrete	$ 96.06	0.11
05	Metals	$ 418.18	0.46
09	Finishes	$ 1010.50	1.11
31	Earthwork	$ 41.682.52	45.97

Table 4.5 – *Continued*

Division	Description	Amount	Percentage of Total (Amount*0.816/Total)
32	Exterior Improvements	$ 28.01	0.03
	Subtotal	**$66,488.75**	
	Location Adjust (81.6%)	$ 54,786.73	
	Allowances	$ 7,476.19	10.01
	Contingency	$ 13,388.66	16.67
	TOTAL	***$ 74,715.50***	100

A division-wise breakdown of the percentage of total estimated costs is shown in Figure 4-2. From this illustration is clearly visible that approximately 46 percent of the direct costs are incurred in Division 31 – Earthwork, and that roughly 26 percent of the direct costs are from Division 1 – General Requirements; 10 percent is incurred in allowances and 17 percent in contingency. These two divisions, the allowance and the contingency take the major part of the total bare costs for the project; only an approximated 1 percent is left over for the rest of the divisions.

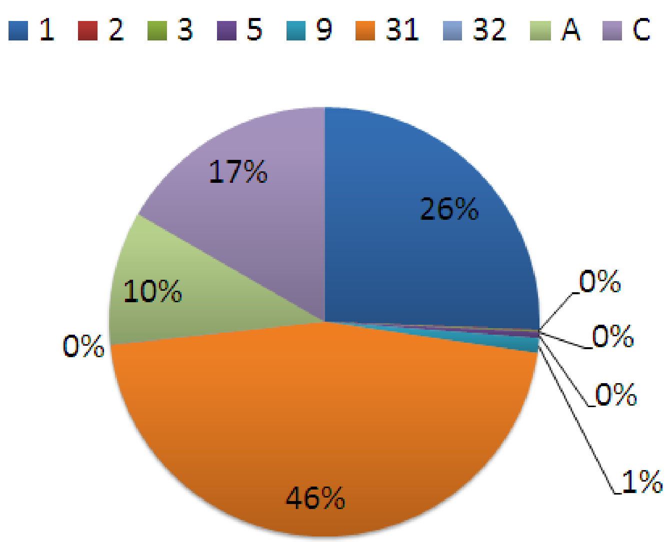


Figure 4-2 Cost Estimate by Divisions

The total amount for the cost estimate may appear high; however, the reader must acknowledge that trenchless technology always bring social cost savings to the general public.

In consequence, an open-cut alternative may yield lower direct costs; however, generating inconveniences and higher social costs to citizens. Social costs are nowadays important due to the awareness growth of environment conservation and quality of life. Social costs for trenchless projects can be as low as 3 to 10 percent of the construction cost, whereas for open-cut it can be as high as several times the value of the direct costs (Najafi and Gokhale, 2006). This statement is better explained by Najafi and Gokhale (2006) pie chart illustrations in Figure 4-3.

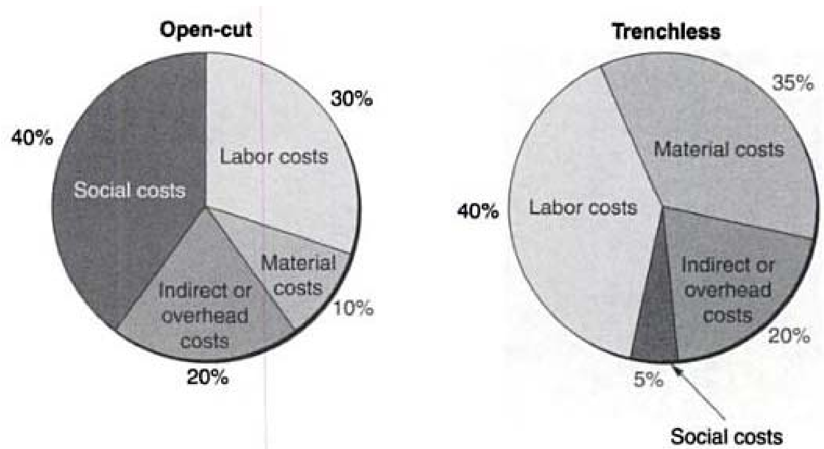


Figure 4-3 Cost Breakdown for Open-Cut and Trenchless

4.7 Estimate Assumptions

The researcher believes that assumptions on a cost estimate greatly depend on the level of design and detail of a project. Due to the theoretical nature of the new methodology presented in this thesis, many project characteristics were assumed; such as soil type, construction site conditions and weather conditions, among other topics. A list of the most remarkable assumptions for the estimate is presented as follows:

- No structure or trees block or interfere on the construction of the work pit.
- The damaged culvert is made of corrugated metal pipe (CMP) and has not collapsed.

- The replacement project is to be performed in a dry season, preferably in summer; therefore, there is no need for bypassing the stream flow.
- Favorable ground conditions in the right-of-way, no need for soil compaction or stabilization.
- Ease pile driving through the road embankment; therefore, the embankment soil is considered relatively homogenous.
- The dimensions of the headwall and wingwall are assumed, they do not have structural design.
- Dimensions for the road are assumed and do not follow any local state or federal state guidelines.
- Rubbish is to be disposed in a landfill at 2 miles (3.2 km) or less.
- Item 31 41 16.10 Ref 0900 was altered to account for horizontal sheet piling of 100 ft (30 m) instead of vertical sheet piling of 40 ft (12.2), labor price has 25% more and equipment price taken off.
- The project location is Fort Worth, Texas.

4.8 Chapter Summary

To better analyze feasibility and as support for future investigations; a theoretical cost estimation is performed in this chapter. The author performed a detail estimate using material quantities generated from technical drawings. The drawings were created for a two-way road with one single line in each direction using the author's best expertise in civil engineering and transportation knowledge. To better organize the quantity takeoff process and the cost estimation, the researcher used the CSI-MasterFormat™ organization structure composed of 50 divisions, which range from general requirements, concrete, metals, to earthwork and electrical power generation. By combining the results of the survey in chapter 4 with cost information from construction cost databases, the researcher was able to meticulously select the recommended items for the job. Interviews with equipment suppliers also help to decide on the rental cost of pipe ramming equipment. In consequence, the analysis resulted in elevated direct costs, which is normal in any trenchless technology project. It is important to acknowledge that trenchless technology brings cost savings to the general public by avoiding major social impacts. The researcher believes that the project created for the cost estimation analysis is the most probable situation in which the new methodology will be useful; however, giving the fact of the higher direct costs incurred, the public may consider shorter installations such as for railroad crossings or for levees crossings.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

It is clear for the researcher that the current state of the culverts in the transportation network is in jeopardy. After the culvert situation is diagnosed, possible solutions were screened in seek of new ideas; ideas that evolved in the invention of the herein explained methodology. The methodology aims enlarge the list of possible solutions to the culvert problematic without claiming to be the best alternative. The method is an environmentally friendly alternative that reduces social costs generated in other construction operations.

This research concludes that there is a wide variety of trenchless methods aimed to renew culverts by lining them from the inside. Replacement of culverts via trenchless is a narrow and unexplored field where possibilities to invent and research can still be found. Moreover, other construction technologies can be applied to trenchless to generate new knowledge.

The development of the theoretical cost estimation did not present major obstacles to the researcher; it was smoothly performed and yielded the most probable direct costs or construction costs. The results of the cost analysis may direct the reader's attention to a high direct or construction costs; nevertheless, the reader should acknowledge the nature of the conceptual stage of the methodology leads to raising contingency values and costs; the reader should also note the inherent social cost savings of trenchless technologies when compared to conventional construction operations.

5.2 Recommendations for Future Research

As part of a continuing effort to research on the herein explored new methodology, the researcher recommends the development and evaluation of a new survey covering topics such as reliability of the estimated direct cost. In this manner the cost estimation performed in this research gets more accuracy. To generate better results, the development of the survey must not delay in time; it may be more useful if performed no later than in the next two years.

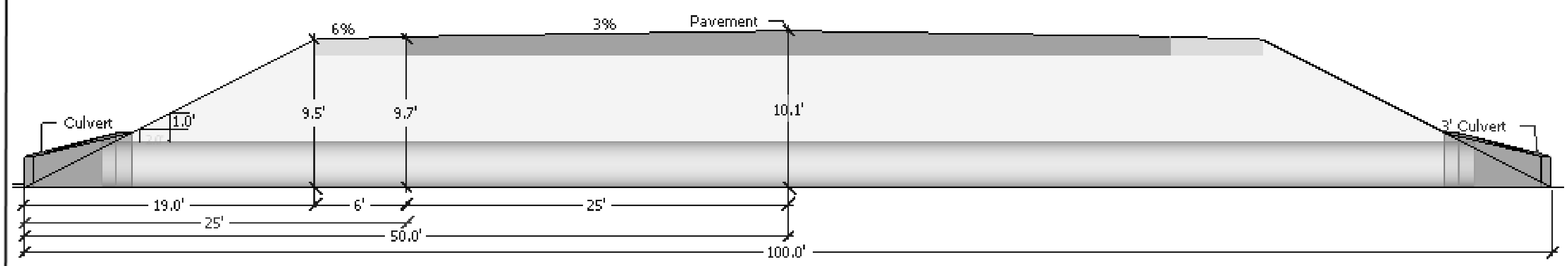
As introduced in section 2.7.2, a cost-benefit analysis can also be performed in the near future as a research topic. The author encourages a cost-benefit analysis if a full scale field trial is performed. The cost-benefit analysis should be studied in all the construction phases before the trial is initiated, during the installation process and after the installation process finishes.

A full scale trial or scale model is advised to prove technical feasibility and constructability of the method. A research on this topic may be jointly shared with geotechnical graduate students and structural design graduate students in order to generate a complete, broader in scope, and reliable report. Research funds to commit this effort may be obtained from the trenchless industry community and/or federal agencies. If a full scale field trial becomes possible in the future, the author recommends a constructability analysis, a productivity analysis and again a cost estimation analysis.

If the herein explained process is to be used in the future for a culvert replacement project, the author recommends an installation length of no more than 100 ft (30.5 m) to avoid welding. The author also recommends its use in railroads, two-way narrow roads, and levees crossings.

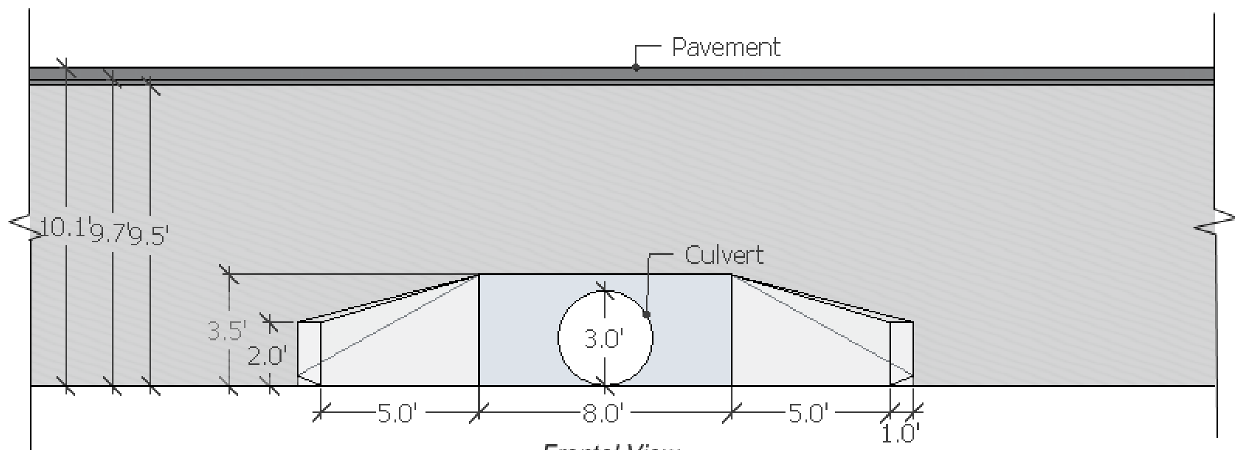
APPENDIX A

THEORETICAL CULVERT REPLACEMENT PROJECT DRAWINGS AND SKETCHS



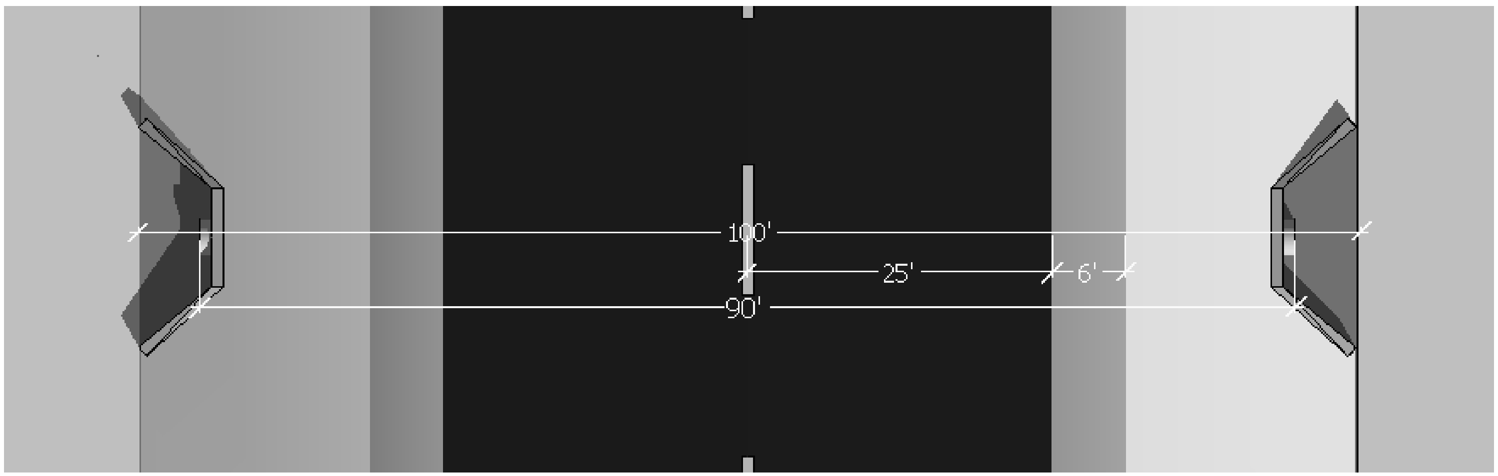
Lateral Section
N.T.S.

Prepared By *Diego Calderon* *Oct - 2009*	*THEORETICAL CULVERT REPLACEMENT PROJECT* *Lateral Section*	*The University of Texas at Arlington* *Department of Civil and Environmental Engineering*



Frontal View
Non Scaled

Prepared By *Diego Calderon* *Oct - 2009*	*THEORETICAL CULVERT REPLACEMENT PROJECT* *Frontal View*	*The University of Texas at Arlington* *Department of Civil and Environmental Engineering*



N.T.S.

Prepared by *Diego Calderon* *Oct - 2009*	*THEORETICAL CULVERT REPLACEMENT PROJECT* *Top View*	*The University of Texas at Arlington*

APPENDIX B

SURVEY QUESTIONNAIRE AND RAW DATA

INTRODUCTION

To better assess the acceptability of the conceptual approach, the author conducted a survey at the ASCE International Pipelines and Trenchless Technology Conference (ICPTT) 2009 in Shanghai, China in both English and Chinese. The general purpose of the survey is to know if there is any feasibility acceptance of the proposed model from the conference participants. The survey is not intended to be used as a research survey; therefore, it does not represent the major body of investigation for this research. The questionnaire is composed of 11 questions, and includes topics regarding awareness of the relation between trenchless technology and culverts, limitations and advantages of the conceptual approach, possible crew size, and installation time.

The respondents were required to input personal details such as name, company, and email; however, these personal details will not be displayed in this research. The responses were tabulated in a spreadsheet to later generate diagrams and better organize the information. A blank questionnaire, the raw data from the spreadsheet and the diagrams for some of the answers are shown in this section. The survey also serves as supporting documentation for the theoretical cost estimation developed in chapter 4.

SURVEY BLANK QUESTIONNAIRE

CUIRE

SURVEY

Please fill out the following questions regarding the horizontal sheet piling process. Your answers will be used for research purposes only, your personal details will not be displayed in the research.

PERSONAL DETAILS

Date: mm/dd/yyyy ______________________

Name: ______________________

Company: ______________________

email: ______________________

QUESTIONNAIRE

1. Are you a? (select one)

☐Student ☐Engineer
☐Professor ☐Contractor
☐Other

2. Have you heard about culvert replacement via trenchless before?

◯ Yes ◯ No

3. From your point of view, which are the major limitations of culvert replacement via trenchless?

☐Cost ☐Materials ☐Other
☐Equipment ☐Experienced Contractors
☐Reliability ☐Length of Installation

4. From your point of view, which are the major advantages of culvert replacement via trenchless?

☐Cost ☐Green Construction ☐Other
☐Social Impacts ☐No pavement disruption
☐Upsize ability ☐Contractor availability

5. Do you think that the proposed methodology is feasible? If no, explain why.

☐Yes ☐No

6. Rate from 1 to 5 the suitability of the new methodology, when replacing culverts made of:

		Less 1	2	3	4	More 5
	Concrete	O	O	O	O	O
	Metal	O	O	O	O	O
	Plastic	O	O	O	O	O
	Aluminum	O	O	O	O	O
Other?		O	O	O	O	O

7. Do you think that the proposed method cann be applied to:

Culverts in railroads?	OYes	ONo
Culverts in highways?	OYes	ONo
Culverts in narrow two way roads?	OYes	ONo
Culverts in airport runways?	OYes	ONo
Other?		

8. Which earth load pressure do you think the author should focus more attention in future investigations?

____

9. Mention a possible crew size for a project using the proposed methodology?

Engineers: ________

On-site workman: ________

Vehicles: ________

Excavators: ________

Other?

10. Suppose a 100 ft (30 m) culvert replacement project is proposed in a non-problematic soil, in how many days do you think the project can be completed?

____

11. Do you think that the new methodology can be useful for something else besides culverts?

OYes ONo

SURVEY RAW DATA

Q1: What is your role in the industry?

Student	1
Professor	1
Engineer	5
Contractor	1
Other	1

Q2: Have you heard about culvert replacement via trenchless before?

YES	56%
NO	44%

Q3: From your point of view, which are the major limitations of culvert replacement via trenchless?

Cost	4	22%
Equipment	2	11%
Reliability	4	22%
Materials	3	17%
Experienced Contractors	2	11%
Length of Installation	2	11%
Other	1	6%

Q4: From your point of view, which are the major advantages of culvert replacement via trenchless?

Cost	1	7%
Social Impacts	4	27%
Upsize-ability	2	13%
Green Construction	2	13%
No Pavement Disruption	6	40%
Contractor Availability	0	0%
Other	0	0%

Q5: Do you think that the proposed methodology is feasible?

YES	7	78%
NO	1	11%
Not Sure	1	11%

Q6: Rate from 1 to 5 the suitability of the new methodology, when replacing culverts made of:

	Concrete	Metal	Plastic	Aluminum	Other
Respondent 1	1	2	2	5	-
Respondent 2	5	5	3	3	-
Respondent 3	5	5	1	2	-
Respondent 4	5	2	1	3	-
Respondent 5	3	3	-	-	-
Respondent 6	2	5	-	-	-
Average =	3.5	3.7	1.8	3.3	0

Q7: Do you think that the proposed method can be applied to:

	YES	NO
Railroads	5	1
Highways	2	4
Narrow	6	0
Airport	4	2
Other	-	-

Q8: Which earth load pressure do you think the author should investigate in the future?

Overloading of vehicles travelling on roads
Theoretical formulas supporting structure, material, technology
Not Sure

Q9: Mention a possible crew size for a project using the proposed methodology

	Engineers	Laborers	Vehicles	Excavators	Other
Respondent 1	1	2	1	1	-
Respondent 2	2	5	2	1	-
Respondent 3	3	10	2	1	-
Respondent 4	1	8	2	1	-
Respondent 5	2	5	1	1	-
Average =	2	6	2	1	0

Q10: Suppose a 100 ft (30 m) culvert replacement project is proposed in a non-problematic soil, in how many days do you think the project can be completed?

Respondent 1	7	
Respondent 2	15	
Respondent 3	30	
Respondent 4	5	
Respondent 5	15	
Respondent 6	5	
Average =	12.8	days

Q11: Do you think that the new methodology can be useful for something else besides culverts?

YES	6
NO	0

SURVEY DIAGRAMS AND RESULTS INTERPRETATION

Question 1; what is your role in the industry?

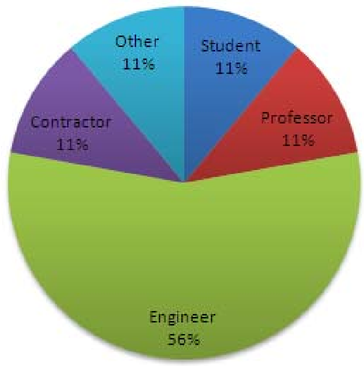


Figure B-1 Survey Participants by Percentages

Question 2; have you heard about culvert replacement via trenchless before?

Not many respondents were aware of culvert replacement via trenchless technology, approximately 6 of every 10 people from the audience have heard about this topic before. Future investigations on culvert replacement via trenchless may raise the awareness on the general public.

Question 3; from your point of view, which are the major limitations of culvert replacement via trenchless?

The respondents had the opportunity of choosing more than one answer. In general, the audience believes that reliability and costs are the two major drawbacks.

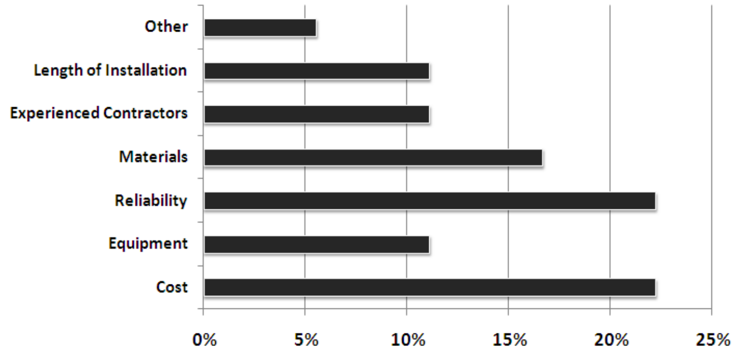


Figure B-2 Limitations of Culvert Replacement via Trenchless by Percentage

Question 4; from your point of view, which are the major advantages of culvert replacement via trenchless?

Non-pavement-disruption advantage is the most remarkable benefit of culvert replacement via trenchless. This advantage almost doubles in preference to the less social impacts advantage. As with any other trenchless technology, the reductions on social impacts remain as another highly attractive advantage of these technologies.

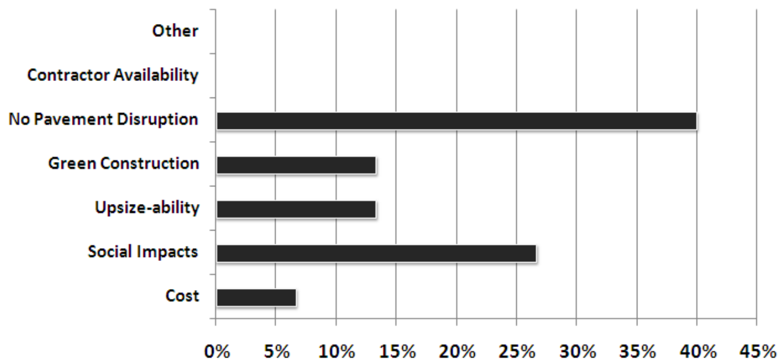


Figure B-3 Advantages of Culvert Replacement via Trenchless by Percentage

Question 5; do you think that the proposed conceptual approach is feasible?

Approximately 80% of the respondents agree with the statement. Nevertheless, approximately 20% of the audience are either not sure of the capabilities of the model or do not agree on the feasibility of the method. The audience believes that the model has lesser seen advantages against lining methods.

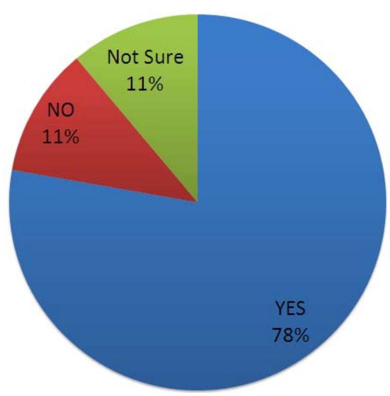


Figure B-4 Feasibility Acceptance of the Conceptual Approach

Question 6; rate from 1 to 5 (1 being less and 5 being more) the suitability of the proposed methodology, when replacing culverts made of: (concrete, metal, plastic, aluminum, and other).

The respondents chose "plastic" as the least favorable culvert material to replace by the proposed methodology. Metal and concrete culverts were marked as the most suitable to be replaced when using the proposed methodology. However, one of the respondents replied that replacement of concrete culverts may be dependent on how easier a fracture-able pipe can be cleaned versus a non-fracture-able pipe.

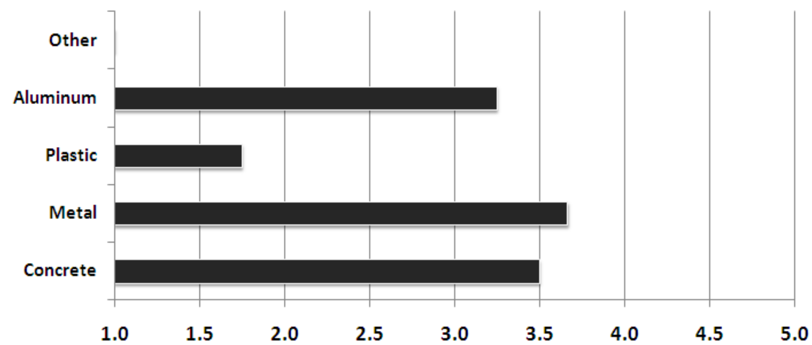


Figure B-5 Suitability of the New Methodology Depending on Culvert Material

Question 7; do you think that the proposed method can be applied to: (culvert replacement in: railroads, highways, narrow two-way roads, airport runways, and other).

The author acknowledges and agrees with a respondent statement, which claims that it depends on how much ground pressure the method can handle and that a better response to this question may be generated after a careful structural design; however, the audience believe that the method may be suitable to replace culverts in railroads, narrow two-way roads, and airport runways. The method may not be suitable to replace culverts in highways, as taken from the survey responses.

Question 8; which earth load pressure do you think the author should investigate in the near future?

There is not a general consensus; however, the respondents believe that topics such as traffic loads imposed over the installation should be studied as well as theoretical formulas supporting structural design, material and technology.

Question 9; mention a possible crew size for a project using the proposed methodology.

In average, the respondents believe that a culvert replacement project using the proposed methodology should include at least the following equipment and labor: two engineers, 6 laborers, two vehicles, and one excavator. This information is of great importance in the cost estimation section of this thesis and gives the researcher a better understanding of the labor and equipment needed on site in a project.

Question 10; suppose a 100 ft (30.5 m) culvert replacement project is proposed in a non-problematic soil, in how many days do you think the project can be completed?

Again the solely purpose of this question is to provide to the researcher a supporting tool to better visualize the duration of a culvert replacement project using the proposed methodology. In average, the respondents believe that a 100 ft (30 m) culvert replacement project will take 13 days using the conceptual approach. Nonetheless, some respondents believe that it may also depend on de diameter of the new installation.

Question 11; do you think that the new methodology can be used for something else besides culverts?

The respondents unanimously believe that the scope of the methodology may also comprehend other structures or environments different from culverts. This question was important to the research because it opens the scope of the method and also opens the discussion for future researches on this technology.

SURVEY SUMMARY

To measure the feasibility of the proposed new methodology, a survey was conducted in a international conference. The survey results show a positive acceptance and feasibility for the culvert replacement methodology. 80% of the respondents believe that the method is suitable to replace culverts; metal and concrete culverts are the two most suitable culverts to be replaced using the new methodology. There is a high tendency from the respondents to acknowledge that the method can be better applied to culvert replacement in narrow two-way roads. In a nutshell, the survey met its objective and aided the researcher on topics such as advantages and limitations, feasibility, crew sizes, project durations, and future research recommendations.

APPENDIX C

QUANTITY TAKEOFF AND COST ESTIMATION TABLES

MATERIAL QUANTITY SHEET

Project: Theoretical Cost Estimation Project
Date: 10/8/2009

Estimator: Diego Calderon
Est #. 1

Div. #: 02 41 DEMOLITION

Ref.	Description	Right-of-way / property line fence length close to culvert (ft)	Total Length (ft)
13.60 - 1600	Fencing, barbed wire, 3 strand	70	70
		Total =	70

MATERIAL QUANTITY SHEET

Project: Theoretical Cost Estimation Project
Date: 10/8/2009

Estimator: Diego Calderon
Est #. 2

Div. #: 02 41 DEMOLITION

Ref.	Description	From concrete demolition (C.Y.)	Subtotal Volume
19.23 3000	Rubbish handling, loading & trucking, including 2 mile haul, chute loaded	1.56	1.56
		Total =	1.56

MATERIAL QUANTITY SHEET

Project: Theoretical Cost Estimation Project

Date: 10/8/2009

Estimator: Diego Calderon

Est #. 3

Div. #: **03 05 COMMON WORK RESULTS FOR CONCRETE**

Ref.	Description	Areas (syd)		Wall Thickness (yd)	Subtotal Volume (cyd)
		Headwall	Wingwalls		
05.10 0050	Selective concrete demolition, break up into small pieces, minimum reinforcing	4.68	9.52	0.11	1.562
				Total =	1.562

MATERIAL QUANTITY SHEET

Project: Theoretical Cost Estimation Project
Date: 10/8/2009

Estimator: Diego Calderon
Est #. 4

Div. #: 05 01 MAINTENANCE OF METALS

Ref.	Description	Circumference (ft)	Lenght (ft)	Total Area (sft)
10.51 6215	Cleaning of structural metal framing, pressure washing	19.70	90	1772.80
			Total =	1772.80

MATERIAL QUANTITY SHEET

Project: Theoretical Cost Estimation Project

Date: 10/8/2009

Estimator: Diego Calderon

Est #. 5

Div. #: 09 97 SPECIAL COATINGS

Ref.	Description	Circumference (ft)	Lenght (ft)	Total Area (sft)
13.23 6940	Exterior steel coatings, two part, epoxy spray	19.70	90	1772.80
			Total =	1772.80

MATERIAL QUANTITY SHEET

Project: Theoretical Cost Estimation Project
Date: 10/8/2009

Estimator: Diego Calderon
Est #. 6

Div. #: 34 41 SHORING

Ref.	Description	Length (ft)	Weight (lb/ft)	Units	Total Weight (ton)
16.10 0900	Sheet piling, 38 psf, left in place	90.00	50.90	12	27.49
				Total =	27.49

MATERIAL QUANTITY SHEET

Project: Theoretical Cost Estimation Project
Date: 10/8/2009

Estimator: Diego Calderon
Est #. 7

Div. #: 32 92 TURF & GRASSES

Ref.	Description	Area from Drawings (sft)		Subtotal Area (M.S.F)
19.13 0800	Grass seed hand push spreader, 4.5 lbs. per M.S.F.	1380.00		1.38
			Total =	1.38

Spreadsheet Cost Estimate Report

Group	Phase	Item	Description	Unit	Quantity	Labor Cost/Unit	Material Cost/Unit	Equipment Cost/Unit	Total Cost/Unit	Total Amount
01 31			**PROJECT MANAGEMENT/COORDINATION**							
	01 31 13.20									
		0120	Field engineer, average	Week	2.6	1165	0	0	**1165**	$ 3,029.00
		0160	General purpose laborer, average	Week	2	1250	0	0	**1250**	$ 2,500.00
		0200	Project manager, average	Week	2.6	1925	0	0	**1925**	$ 5,005.00
01 54			**CONSTRUCTION AIDS**							
	01 54 33.20									
		0150	Excavator, diesel hydraulic, crawler mounted, 1 C.Y. cap.	Day	10	-	-	-	**590**	$ 5,900.00
		4260	Tractor, crawler, with bulldozer, torque converter, diesel 200 H.P.	Day	2	-	-	-	**1025**	$ 2,050.00
	01 54 33.40									
		0600	Air compressor, portable, diesel engine, rotary screw, 600 C.F.M.	Day	8	-	-	-	**195**	$ 1,560.00
		6410	Toilet, portable chemical	Day	13	-	-	-	**18.35**	$ 238.55
	01 54 33.60									
		3900	Hoists, chain type, overhead, manual, 10 ton	Day	9	-	-	-	**7.35**	$ 66.15
	01 54 33.40									

Group	Phase	Item	Description	Unit	Quantity	Labor Cost/Unit	Material Cost/Unit	Equipment Cost/Unit	Total Cost/Unit	Total Amount
		6350	Torch, cutting, acetylene-oxygen, 150' hose	Day	2				**21.5**	$ 43.00
	01 54 36.50									
		0020	Dozer mobilization, above 150 HP	Ea	1	85	0	261	**346**	$ 346.00
		0020	Dozer demobilization, Above 150 HP	Ea	1	85	0	261	**346**	$ 346.00
		0020	Excavator mobilization	Ea	1	64	0	117	**181**	$ 181.00
		0020	Excavator demobilization	Ea	1	64	0	117	**181**	$ 181.00
		0020	Small equipment mobilization	Ea	1	64	0	117	**181**	$ 181.00
		0020	Small equipment demobilization	Ea	1	64	0	117	**181**	$ 181.00
01 56			**TEMPORARY BARRIERS & ENCLOSURES**							
	01 56 23.10									
		0800	Traffic cones, PVC, 18'' high	Ea	10	0	8.4	0	**8.4**	$ 84.00
01 71			**EXAMINATION AND PREPARATION**							
	01 71 23.13									
		1200	Crew for layout of building, trenching or pipe laying, 3 person crew.	Day	1	1025	0	70	**1095**	$ 1,095.00
01 71			**EXAMINATION AND PREPARATION**							
	01 71 23.19									

Group	Phase	Item	Description	Unit	Quantity	Labor Cost/Unit	Material Cost/Unit	Equipment Cost/Unit	Total Cost/Unit	Total Amount
		0020	Surveyor stakes hardwood, 1" x 1" x 48" long	C	0.2	0	58	0	58	$ 11.60
01 74			CLEANING AND WASTE MANAGEMENT							
	01 74 13.20									
		0020	Cleaning up, minimum	Job	1	-	-	-		$ 200.73
										$ 23,199.03
02 41			DEMOLITION							
	02 41 19.23									
		3000	Rubbish handling, loading & trucking, including 2 mile haul, chute loaded	C.Y.	1.56	23	11.85	0	34.85	$ 54.44
										$ 54.44
03 05			COMMON WORK RESULTS FOR CONCRETE							
	03 05 05.10									
		0050	Selective concrete demolition, break up into small pieces, minimum reinforcing	C.Y.	1.6	53.5	0	8	61.5	$ 96.06
										$ 96.06
05 01			MAINTENANCE OF METALS							
	05 01 10.51									
		6215	Cleaning of structural metal framing, pressure washing	S.F.	1772.80	0.03	0	0	0.03	$ 53.18

Group	Phase	Item	Description	Unit	Quantity	Labor Cost/Unit	Material Cost/Unit	Equipment Cost/Unit	Total Cost/Unit	Total Amount
05 05			**COMMON WORK RESULTS FOR METALS**							
	05 05 21.10									
		0100	Hand burning, incl. preparation, torch cutting and grinding, steel to 1/2" thick	L.F.	250	1.17	0	0.29	**1.46**	$ 365.00
										$ 418.18
09 97			**SPECIAL COATINGS**							
	09 97 13.23									
		6940	Exterior steel coatings, two part, epoxy spray	S.F.	1772.80	0.29	0.28	0	**0.57**	$ 1,010.50
										$ 1,010.50
31 41			**SHEET PILING**							
	31 41 16.10									
		0900	Sheet piling, 38 psf, left in place	Ton	27.49	150	1300	0	**1450**	$ 39,854.70
		2700	High strength pilling, 50,000 psi	Ton	27.49	0	66.5	0	**66.5**	$ 1,827.82
										$ 41,682.52
32 92			**TURF & GRASSES**							
	32 92 19.13									
		0800	Grass seed hand push spreader, 4.5 lbs. per M.S.F.	M.S.F.	1.38	1.4	18.9	0	**20.3**	$ 28.01

Group	Phase	Item	Description	Unit	Quantity	Labor Cost/Unit	Material Cost/Unit	Equipment Cost/Unit	Total Cost/Unit	Total Amount
										$ 28.01
									Subtotal =	$ 66,488.75
			Price correction by location (81.6%)						Subtotal =	$ 54,786.73
			ALLOWANCES							
		0001	Pipe ramming rent, 12" diameter	Month	0.43				10000	$ 4,333.33
		0002	Cone adapter rent	Week	1.14				1000	$ 1,142.86
		0003	Cone adapter rotator, make	Ea	1				2000	$ 2,000.00
			CONTINGENCY							
			Added to subtotal						20%	$ 12,452.58
									TOTAL	$ 74,715.50

APPENDIX D

GLOSSARY

The following glossary has been extracted from the report entitled “An Asset Management Approach for Drainage Infrastructures & Culverts,” authored by Najafi, et al, (2008).

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 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 use 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, nor 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 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 expose 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 4,000 mm (10 in. to 160 in.) according to FHWA Highways in the River Environmental 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 (20ft) 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 environmental 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-ohms 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 environmental.
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 opening 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	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 divides by the length of that part of its periphery in contact with its containing conduit; the ratio of area to wetted perimeter.
Hydrology	The science of water related to its properties and distribution in the atmosphere, on the land surface, and beneath the surface of the land.
Improved Inlet	An improved inlet has an entrance geometry that decreases the flow constriction at the inlet and thus increases the capacity of the culverts.
Impermeable Strata	It is a stratum in which texture is such that water cannot move perceptibly through it under pressures ordinarily found in subsurface water.
Impervious	It is impermeable to the movement of water.

Impingement	Suspended solid particles or gas bubbles in water striking the surface or turbulence along breaking down the protective layer of a metal or a concrete surface.
Infiltration	The flow of a fluid into a substance through pores or small openings. It connotes flow into a substance in contradistinction to the word percolation, which connotes flow through a porous substance.
Inflow	The rate of discharge arriving at a point (in a stream, structure, or reservoir).
Inversion Lining	Process of inverting pliable tube into existing pipe with hydrostatic or air pressure to reline existing pipe. The tube is forced against the existing pipe and thermosetting resins to provide structural strength and improved smoothness.
Invert	The invert is the flowline of a culvert (inside bottom) or the flow line in a channel cross section, pipe, or culvert or the lowest point in the channel cross section or at flow-control devices such as weirs or dams.
Inundate	To cover or fill as with a flood.
Joint	A connection between two pipe sections made either with or without the use of additional parts.
Lateral	A conduit, ditch, canal, or channel conveying water diverted from a main conduit, canal, or channel for delivery to distributaries; sometimes considered a secondary ditch.
Launching	Release of undercut material (stone riprap, rubble, slag, etc.) down slope; if sufficient material accumulates on the stream bank face, the slope can become effectively armored.
Link Pipe Lining	Method of pulling a short, pipe line segment to the damaged point in an existing pipe and jacking the segment into place.
Load (or sediment load)	The amount of sediment being moved by a stream.
Long Span Culverts	These culverts are designed on structural aspects rather than hydraulic considerations. Usually constructed of structural plates, which exceed defined sizes for pipes, pipe arches, arches or special shape that involve a long radius or curvature in the crown or side plates.
Manning's Equation	An equation for the empirical relationship used to calculate the barrel friction loss in culvert design.

Meander	The winding of a stream channel. Any reverse or letter-S channel pattern fashioned in alluvial materials by erosion of the concave bank, which is free to shift its location and adjust its shape as part of a stage in the migratory movement of the channel as a whole down an erodible, alluvial valley.
Metal Corrosion	It is an electrical process involving an electrolyte (moisture), an anode (the metallic surface where oxidation occurs), a cathode (the metallic surface that accepts electrons and does not corrode), and a conductor (the metal pipe itself).
Minor Head Losses	Head lost through transitions such as entrances, outlets, obstructions, and bends.
Moisture	Water diffused in the atmosphere or the ground.
Normal Flow	Normal flow occurs in a channel reach when the discharge, velocity and depth of flow do not change throughout the reach. The water surface profile and channel bottom slope will be parallel. This type of flow will exist in a culvert operating on a steep slope provided the culvert is sufficiently long.
Outfall	The discharge end of drains or sewers.
Outlet Control	A condition where the relation between headwater elevation and discharge is controlled by the conduit, outlet, or downstream conditions of any structure through which water may flow.
Parameter	A characteristic descriptor, such as a mean or standard deviation or sometimes considered as a variable comprised of the product of two or more variables.
Peak Discharge	The highest value of the stage or discharge attained by a flood; thus, peak stage or peak discharge.
Permeability	The property of a material that permits appreciable movement of water through it when it is saturated and movement is actuated by hydrostatic pressure of the magnitude normally encountered in natural subsurface water.
Perforation	Complete penetration of metal culvert that generally occurs in the invert.
pH Value	The log of the reciprocal of the hydrogen ion concentration of a solution. The pH value of 7.0 is neutral; values of less than 7.0 are acid; values off more than 7.0 are basic.

Pipe	A tube or conduit.
Pipe Diameter	The inside diameter of a pipe.
Pipe 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 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.

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BIOGRAPHICAL INFORMATION

At the time of the defense, Diego Calderon has a Bachelor of Science in Civil Engineering from Universidad Industrial de Santander in Colombia and a modest background in construction management. While pursuing a Master of Science from The University of Texas at Arlington (UT Arlington) and since his arrival to the United States (U.S.) he has been involved in research projects related to trenchless technology topics. Mr. Calderon has achieved high degrees of academical development in UT Arlington; proof of that is the scholarship award for Masters and Ph.D. students received in fall of 2008. He has also given technical presentations at nationally and internationally recognized conferences such as in the American Society of Civil Engineers (ASCE) Pipelines Conference of 2009 in San Diego, California or for the ASCE International Pipelines and Trenchless Technology Conference of 2009 in Shanghai, China. For the near future Mr. Calderon plans to continue his participation in trenchless technology industry in the U.S. by working for the National Association of Sewer Service Companies in Owings Mills, Maryland.