Cost Effective Manhole to Pipe Connection

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COST EFFECTIVE MANHOLE TO PIPE CONNECTION

UTKARSH SHEKHAR

A Major Project

Submitted to the Graduate College of Bowling Green State University in partial fulfillment of the requirements for the degree of

MASTERS OF CONSTRUCTION MANAGEMENT TECHNOLOGY

Construction Management

Chair of committee, Dr. Alan Atalah
Committee member, Dr. Charles Wayne Unsell

May 2016
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ABSTRACT

The manhole to the pipe connection is an important part of the sewer system. Any problem in the seal connecting the manhole to the pipe results into either inflow of ground water into the sewer system or outflow into the surrounding environment. The inflow of ground water on one hand increases the volume of wastewater being sent to the wastewater plant and on the other hand, the outflow leads to the contamination of the surrounding soil. Hence, the durability and longevity of the manhole to the pipe connection is crucial.

The manhole to the pipe connection generally fails due to two main reasons: external forces and internal problems. The external forces lead to the failure of the connection externally, while the internal failures occur due to the failure of the seal materials. It is important to take steps to improve the durability of the seals connecting the manhole to the pipe connections. The life of the seal is increased by creating resistance to the external forces and by bringing improvement in the internal structure of the seal materials.

A cost model was developed for the various types of the seal materials and this was done using the concept of the equivalent annual cost. The type of the seal material with the lowest equivalent annual cost was the most economical kind of the seal material.
ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my project chair, Dr. Alan Atalah, for his valuable guidance and constructive criticism throughout the course of this research. I am also very thankful to Dr. Charles Wayne Unsell, for being the committee member of my project and providing me with continuous guidance. I would like to thank Dr. Arpan Yagnik for reviewing my document.

I want to express my sincere thanks to all of my friends and the faculty members at Bowling Green State University for making my academic life memorable. Finally, I will like to thank my parents and my family members for their continuous support and encouragement during my studies at Bowling Green State University.
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CHAPTER I
INTRODUCTION

Large volume of wastewater passes through sewer lines each day. Since the seal gasket joins the manhole to the pipe in the sewer line, the manhole to the pipe connection should be watertight to prohibit any inflow of groundwater or outflow of wastewater. When the manhole to the pipe connection fails, the inflow of the groundwater increase significantly or/and wastewater outflow from the sewer into the surrounding environment increase polluting the nearby soil. Due to the inflow of the groundwater into the sewer, wastewater treatment plants are treating huge volume of extra wastewater each day (Tillman G. M., 1996)

When the connecting seal fails in region of high water table, the groundwater starts seeping into the sewer through the manhole to the pipe connection. A research study in the UK showed that in region of high water table, the water infiltration rate is as high as 120 l/head/day. This has increased the pressure on the wastewater treatment plants. They are treating higher volume of wastewater due to infiltration and it is causing losses to the wastewater treatment plants (Ellis, 2001).

Figure 1: Sewer infiltration (Skipper, n.d.)
Due to the failing of the connecting seals, the wastewater starts seeping into the surrounding environment, thus contaminating the surrounding soil. When the leaking fluid contains chemicals, it escalates the problem of contamination of soil. If the sewer system is deep in the biologically active part of the soil, the leakage directly mixes with the groundwater and contaminates the potable water (Rail, 1989).

The failure of the manhole to the pipe connection leads to major problems. On the one hand it affect the well-being of the society by contaminating its drinking water and the surrounding soil and on the other hand, it is causing loss to the water treatment plants by increasing the volume of wastewater being treated. These problems reflect the importance of the connecting seal between the manhole and the pipe in the sewer system.

The manhole and the pipe connection exists since the era of the ancient Rome. The pipes then were made of clay and terracotta, and leather was used in the pipeline for sealing. However, with time the manhole and the pipe connection kept on evolving (Dembskey, 2009). In the modern time, there are two different varieties of seal connections available for the manhole to pipe connection, they are the traditional seal system and the modern seal system. The traditional seals have relatively low life, but they are efficient in performance. While the modern seals have longer-design life, they are relatively expensive.

Burlap with mortar is used for sealing the manhole to the pipe connection, and mortar with natural fiber like wool or cotton has been used for sealing. They are the traditional sealing system with low initial cost, but due to low life and maintenance, the total cost increases (Construction, 2008). However, the modern seal system is technically advanced and has longer life than the traditional
seals, but it is expensive and fails occasionally. They are the compression type seals, boot type seals, nitrile seals and cast-a-seals (Seal, 2008).

One of the major issues with the longevity of traditional seal system is the microbial induced corrosion with strong detrimental effects. Anaerobic bacteria create hydrogen sulfide gas in the sewer line, which mixes with the humidity in the sewer line creating sulfuric acid, which reacts with cement and dissolves it (Manhole Corrosion, 2013). This project is concerned with researching major problems faced by the seals connecting manhole to the pipe. There are different types of materials available in the market, which can be used to seal the manhole to the pipe connection. However with time, most of the seal materials malfunction and there is either infiltration or outflow.

There are criteria like topography, climate, cost of labor and difficulty of excavation that increases the cost of installation and maintaining the seal connection (Water, 2002). Since there are different kinds of seals available in the market, it is important that the seal being used be economical. Different types of seal are used in different environmental condition, but in heavy-rain or/and high ground-water-table conditions, the situation worsen due to the increasing infiltration/outflow rates. The main concern is what can be done to enhance the seals to last longer economically.

The pipe material and the manhole material are important while deciding the seal for the manhole to the pipe joint. The joint conditions for the rigid pipe are simple compared to the flexible pipes. While the rigid pipes are made of mortar or reinforced concrete, the flexible pipes are made of PVC, HDPE and similar other compounds.
1.1 Problem Statement

Eventually the seal material used at the manhole to pipe connection fails causing increased infiltration or outflow rate. Some seal materials have longer life, while there are some with shorter life. The traditional systems of sealing the manhole to pipe connection need change; especially, when the new emerging systems are technically advanced and efficient and more importantly available. However, the modern seals are expensive compared to, the old systems that are economic and simple, which do not last longer leading to higher total cost. Many external and internal factors are the main reasons for the failure of the seal materials. It is important to research various reasons of the failure of the seal materials to bring improvement.

1.2 Research Objective

The research aims at improving the various seals used at the manhole to the pipe connection. The research aims at making the seals more efficient, cheaper, less risky and less prone to error. It aims at developing a cost model for the various types of the seals, then proposing the most efficient kind of the seal system. As a poor connection between the manhole and the pipe leads to problems and increases the cost.

1.3 Significance of Study

The failure of the seal materials leads to the increases in the cost. This research is important since it will study the major problems existing with the seal system, their main reasons of the failure and the ways to improve it. This study is pertinent because it will lead to a better, efficient and economical seal material and mechanism for the manhole to the pipe connections. This research will help by making the seals more efficient, less risky and less prone to error. The rigid and the flexible pipes behave differently; therefore, specific seals need to be used for different system.
CHAPTER II
LITERATURE REVIEW

Manholes have been in use since the Romans era. Earlier there were mainly the rigid pipes, but later on the flexible pipes started to be used. The flexible pipes and the rigid pipes have their own different kinds of sealing system, but it was common to use traditional seals over the rigid pipes. However, with time various methods have been developed to seal the manhole and the pipe connection (Sewer History, 2004).

2.1 Traditional Seals

The traditional types of the seals have been in use for a long time and they are still in use in many countries. The traditional seals used for the manhole and the pipe connections are:

(i) Burlap with Mortar

(ii) Mortar mixed with biological fiber

(iii) Fiber glass mixed with mortar

2.1.1 Burlap with Mortar

Burlap with mortar is created by mixing the mortar with the burlap fiber. This system of seal is cheap and easy to use and that is why it has been in use since long time and still being used in the developing countries. Usually mortar when sets is brittle and the elastic strength of the solid mortar is less, when compared to the modern seals. Therefore, it is needed to increase the elastic strength of the mortar to be able to be used as the seal material for the manhole to the pipe connection (Harris, 1973).
The burlap with mortar seal is mainly created by soaking the loosely made burlap with a modified kind of fast setting cement. Then, this wet burlap is set around the pipe structure that is then inserted inside the manhole opening and the connection is set. When the cement soaked burlap solidifies, it creates a watertight connection at the manhole to the pipe connection. The burlap-crete has extreme resistance to weathering and it shows long life even in the adverse situation. This seal system does not delaminate, swell, mold and rot, while it is easy to be created and installed cheaply. Thus these qualities increase the life of the burlap seals to a high extent (Construction, 2008).

2.1.2 Mortar mixed with Biological fiber

Adding the biological fiber in the mortar results in an increase in the strength of the mortar. We are able to use them as a seal material in the manhole to the pipe connection by adding these fibre. Two part of sand is mixed with one part of the Portland cement and to this mixture the fiber is mixed with emulsified acrylic. This increases the elastic strength of the system on one hand and the total strength on the other. They prove to be a good option for a cheap and durable manhole to the pipe connection (Connelly, 2008).
The mortar is mixed with the long wool fibers and the wet mixture is wrapped around the pipe at the end corner. Then, the pipe is inserted into the manhole opening and the system is allowed to dry. When the system dries, it locks the whole system and makes the system watertight and durable. The mixture has good elastic and plastic strength, while they have good tensile as well as the compressive strength. The existence of the cellulose in the fiber gives them long life and durability.

The process of making this seal is easy and fast and it saves a lot of labor and time. Adding another preservative like the borax and chikusaku-eki (a byproduct of bamboo ash burner) increases the efficiency and the life. The seal is low weight, has long life and it has low maintenance cost. However, when the right cement is not used and the elastic components are not added in the right amount, the seal loses its strength and eventually fails (Y.R. Alston, 1990).

### 2.1.3 Glass Fiber mixed with Mortar

The fiber glass mixed mortar is also used to seal the manhole to the pipe connection. The mixing of the fiber to the mortar improves the toughness of the seal system and increases the waterproofing
ability of the seal. This happens due to the fiber bridging mechanism of the mixture, which increases the plastic and the elastic properties of the seal and simultaneously increases its efficiency (Silpro, 2010).

![Figure 4: Mortar mixed with glass fiber (Silpro, 2010)](image)

The process of the installation is easy and simple. Firstly, the fiber mixture is created with the cement and other additives. Then, the pipe is cleaned by pressure cleaning or by acid cleaning and then the wet mixture is applied over the end of the pipe. The pipe is then set into the manhole to dry, once the setup dries it seals the system and provides waterproof joint.

The use of the fiber in the mortar helps a lot in increasing the tensile loading strength of the system. It drastically reduces the rate at which the crack propagates as well as this mixture shows a very good performance in controlling the matrix micro cracking (Goyal, 2013).

When the fiberglass mortar matrix cracks, the system shows strong pseudo ductile behavior and still keeps on holding the system by showing a high load bearing capacity even from that place. Fiberglass is blended with the mortar and that gives it energy absorbing mechanism which ultimately leads to the late formation of the micro cracks. The mixture of the fiberglass and the
mortar creates a lot of bubbles and foam, which usually gives a bad texture to the drying seal system and weakens the seal structure (Jeffrey Girard, 2016).

2.2 Nitrile Seals

When the connecting seal at the manhole and the pipe connection is exposed to the petro and the solvent based chemicals, then gaskets that are made from the NBR Nitrile are being used to handle that condition, which are chemically resistant (Sealing Products for Oil and Chemical Resistance, 2015).

2.2.1 Nitrile Pipe Gaskets

The nitrile pipe gaskets are used for the concrete pipe sealing and these gasket are resistant towards most of the hydrocarbon chemicals. When the pipe and the manhole connection comes under the chemically contaminated soil, it becomes important to save the seal from getting damaged. Under such circumstances the chemically resistant seals are used, which also fulfill the ASTM standards (Sealing Products for Oil and Chemical Resistance, 2015).

![Figure 5: Nitrile Pipe gasket (Seal, 2008)]
Installation of the nitrile seals is done by fixing the spigot part with the bell part. At the connection point the one system holds the seal and the other system covers it up and by compression they seal the system. The seal gasket is fixed on the spigot and then the bell part covers it up, creating the seal system. While putting the seal gasket on the pipe, it is made sure that the gasket is fixed firmly.

Lubricating the spigot and bell system is an important aspect of the installation, it helps in the smooth fixing of the system and reduces the friction at the joint. Lubricant is applied in the bell part of the pipe at the leading edge, while at the same time it is applied over the body of the seal gasket material. Then, the pipe is inserted in the manhole pipe opening and the system is set. However, the sharpness of the edge of the groove is checked, so that it does not damage the seal during installation (Seal, 2008).

These seals are resistant to the acids attacks and they are also resistant to the various types of the oils like the petroleum oil, the vegetable oils and the oils derived from the minerals. On the one hand they are resistant to a large range of aromatic hydrocarbons, and on the other hand they are also resistant to heat aging. However, they are better in quality than the seals made up of neoprene rubber.

These seals are vulnerable to the problem of the differential settlement and they also fail in the case of high water pressure in the pipelines. Usually the friction at the pipe and the manhole connection leads to the wearing and the tearing of the seal and this wearing and tearing damages the efficiency of the seal gaskets, which ultimately leads to the failure of the connection system. Once the system fails, the leaking starts and if the water pressure in the area is high, the leaking
escalates. However, the main problems that the gasket nitrile seal faces are the friction, wear and tear, seal-ability, stability, extrusion and conform-ability.

2.2.2 Nitrile Pre-Lubricated Pipe Gasket

The nitrile pre-lubricated pipe gaskets are known for their efficiency and reliability in sealing the pipe and the manhole. They are mainly used to seal the concrete pipes and the concrete manholes. They are made of the synthetic nitrile butadiene rubber and hence, they have good resistance to the petro chemicals and the hydrocarbons.

![Figure 6: Nitrile Pre-lubricated pipe gasket (Seal, 2008)](image)

These seal gaskets are easy to install on the pipe and they are just needed to be fixed on the spigot part of the pipe system. They can be installed fast and they save expenses related to the labor. It is easy for the laborers to install and hence, it saves them from being in the ditch for long.

The one advantage of the nitrile pre-lubricated pipe gasket is that it does not need any lubrication beforehand to fix the system to the pipe. It saves cost on the one hand and leads to fast installation on the other. The flaps of the gasket already have internal lubricant, which negates the need for
applying any extra lubricant to the system. Since the flap of the nitrile pre-lubricated gasket gets set into the annular space of the pipe, it reduces the impact of the differential settlement (Seal, 2008).

### 2.2.3 Nitrile water stops

Nitrile waters stop seals are used over the grout sealing, while they are not actually used as a complete seal, but they act as a backup support to the grout sealing. They are applied over the cracks to cover up the infiltration in the connection system. They are considered effective in dealing with the problem of the groundwater infiltration in the sewage system. Since these seals are used with the grout seals, their use is very limited.

Whenever the manhole and the pipe joint fail because of the cracks in the grout, then there is a need for covering up the cracks in the grout to stop the groundwater infiltration, then these nitrile water stops are used over the grout. The nitrile water stops are secured to the pipe by using the stainless steel clamps and they are fixed in the area of the grout failure. This rubber covering stops the infiltration in the system and its installation is fast and labor free (Seal, 2008).

![Figure 7: Nitrile water stops (Seal, 2008)](image)
They are mainly applied over the cracks to cover-up the infiltration in the cementitious grout connections. Using the epoxy grout instead of the cementitious grout actually improves the life of the seals. Since the water stops are made up of nitrile rubber, they are resistant to the petroleum solvent and the chemicals.

![Diagram of nitrile water stop section](image)

**Figure 8: Nitrile water stop section (Seal, 2008)**

### 2.3 Cast-a-seals

Cast-a-seal connectors are fixed into the manhole at the time of the pouring of the manhole and they come up as a part of the manhole. Since they are installed into the manhole at the time of pouring, they save a lot of time of installation and the labor cost. These seals are rigid in their size and come with a fixed size, but they are flexible connectors (Cast-A-Seal Pipe Connectors, 2015).
2.3.1 Cast-a-seal 12-08 manhole connector

The Cast-A-Seal manhole connectors are the boot type of the seal connectors that are used for the 8 inch pipe to manhole connections. These manhole connectors are flexible type of the connectors. However, their properties resemble with the boot type connectors and their structure also similar.

![Cast-a-seal 12-08 manhole connector](image)

**Figure 9: Cast-a-seal 12-08 manhole connector (Cast-A-Seal Pipe Connectors, 2015)**

Cast-a-seal manhole connectors are installed in the manhole structure, when the manhole is created by pouring the concrete. The seal are placed in the forming structure at the required position and the key lock of these seals are fixed in the manhole. When the pipe is inserted in the manhole, the seals are opened up and they are fixed to the pipe with the help of the steel clamps, thus creating watertight seal. The key locks are responsible for the watertight connection between the manhole and the seal, which provides a base for installing the seal (Cast-A-Seal Pipe Connectors, 2015).

Since the design is simple and the seals are installed in the manhole system at the time of the pouring, it totally eliminates the cost of the groove creation in the manhole concrete structure. As this seal is rigid about its size, it is easy to cut the damaged seal out of the manhole structure and replace by a new one. In this process the key lock makes the replacement of the seal easy. However,
there is a limited flexibility in the size of the pipe system and a single manhole can be used for only for pipe of one size. They have not found out to perform well, when exposed to chemical contamination. Sometimes the seal fails due to the failing of the key locks and sometime steel clip used to set the seals corrodes and leads to failure.

2.3.2 Cast-a-seal 802 connector

Cast-a-seal 802 connectors are used for large diameter pipes with diameters more than 18 inches. It is a technically advanced kind of seal material that is available in the market, but it is actually a cast in boot style connector. One of the advantage for this seal system is that it can be made for almost any pipe diameter and it can be used into the system very easily using rolled steel ring mandrel. This connector exceeds the ASTM standards of the connector seal (Cast-A-Seal Pipe Connectors, 2015).

![Image of Cast-a-seal 802 manhole connector](image)

**Figure 10: Cast-a-seal 802 manhole connector (Cast-A-Seal Pipe Connectors, 2015)**

The process of installing the seal system in the manhole structure starts with the installation of the key lock of the seal system in the structure of the manhole. The key lock system is installed in the
manhole structure while pouring. Since the diameter is large, presence of the key locks in the manhole structure ensures the watertight connection. The seal system is set to the key lock in the manhole and then the pipe is inserted into the system.

The connector seals have high resistance to the chemicals as per the ASTM testing and they show no damage when exposed to the chemicals like sulphuric acids. They also have high value of the tensile strength. As per the ASTM testing, the minimum required tensile strength is 1200 PSI, but the tensile strength of the system is found out to be 2100 PSI. The seal system has a good elongation level at the time of the breaking, as the ASTM standards requires an elongation of 350%, but it has been found out that they show an extension level of 525% at the time of the break (Cast-A-Seal Pipe Connectors, 2015).

2.3.3 Cast-a-seal 964

These are efficient system of seals that can be used in manhole and the straight wall system. They have casting mandrel that makes the installation easy and makes them flexible in their use. They have dual step fixing and they can accommodate all pipes with diameter ranging from 107-175 mm. Since the system of the seal is produced by casting into the manhole structure at the time of the pouring of the concrete, it makes the process efficient and fast. As the seal structure is cast into the system, no labor hours are needed upon the process of coring holes into the system.
The rubber used in the seal usually goes through a lot of testing and so performance of the rubber gasket has been found out to be good. At the time of the pouring of the concrete, the seal system is cast into the manhole and the key locks are set into the manhole structure. As the system of the seal is created by casting the key lock into the manhole while the concrete is poured, it ensures the water tightness of the seal. It is then, the pipe is set across the seal and the installation is made complete. These seals have the ability of the dual step fixing and because of this ability, these seals can be installed with different diameter pipes in a fixed range. The range of diameters for cast-a-seal 964 system is between 107-175 mm. When the seal system is damaged, it is easy to cut the rubber seal gasket out of the system and then install the system with a new seal gasket (Cast-A-Seal Pipe Connectors, 2015).

2.4 Boot type manhole connector

The boot-type-manhole connectors are the flexible connectors with the ability to create more direct rubber deformative force. They have been found to be efficient in their performance. These
manhole connectors are designed to handle the problem of the differential settlement and the tilting of the connection (Boot-Type Manhole Connectors, 2015).

2.4.1 Direct drive manhole connector

Direct drive is the premium type of the manhole connector available in the market, which is corrosion resistant and has a long life. It uses ADS pipe adapter between the pipe and the seal, which helps in better connection between the pipe and the manhole. This seal meets all the ASTM standards, while the seal system uses a stainless steel power sleeve and it has an adjuster that makes the installation fast and easy. This system has no weld or rivets and it is in the range of the most competitive seal in the market with no plastic part in the system (Boot-Type Manhole Connectors, 2015).

![Direct drive manhole connector](image)

**Figure 12: Direct drive manhole connector (Boot-Type Manhole Connectors, 2015)**

The installation process of the direct drive manhole connector is smooth and fast. The one end of the manhole connector is fixed to the manhole and the other end is being fixed to the PVC pipe. However, the important thing about this installation is that the other side of the manhole connector that is connected to the pipe has options for three different diameters. They are 38-51 mm, 75 mm
and 100 mm. For different required dimensions, the seal connector is cut and the pipe is set into the system, thus providing an efficient and fast setup (Boot-Type Manhole Connectors, 2015).

All the components of the manhole connector are made up of stainless steel and no rivets or screws are being used, hence they show good resistance to corrosion. They have a long length, which gives them strong resistance towards handling the differential settlement and provides better scope for the flexible water tightening. The direct drive manhole connector uses the ADS pipe adapter that is a new feature for the manhole to pipe connection. This rubber pipe adapter is set as the connection between the direct drive connector and the installed pipe. It provides excellent support for the watertight sealing (Boot-Type Manhole Connectors, 2015).

### 2.4.2 Nylo drive manhole connector

The Nylo drive manhole connectors are similar to the direct drive manhole connectors. However, they have a strong advantage over the direct drive manhole connectors, as they have power sleeve made of nylon polymer with stainless steel inserted inside it. They are resistant to the chemicals and they use the nitrile rubber for its manufacturing.

![Nylo drive manhole connector](image)

**Figure 13: Nylo drive manhole connector**

(Boot-Type Manhole Connectors, 2015)
The Nylo drive manhole connector is meant for wet conditions, it is therefore efficient to be used in the wet wells, in the concrete manholes and in the storm water structures. This seal system can be installed easily and so it saves labor cost and time. All the take-up clamps of the manhole connector are made up of the stainless steel, which have a definite corrosion resistance increasing the longevity of the seal connector. The power sleeve used in the system works on the concept of the expansion installation mechanism, which makes it efficient. The power sleeve is made up of the reinforced nylon polymer and it has the stainless steel inserted in it (Boot-Type Manhole Connectors, 2015).

2.4.3 Positive seal manhole connector

Positive seal manhole connectors are the high power and flexible manhole to the pipe connector; they have high performance quality and long life. They are quick to be installed in the connection and are known for this quality.

![Positive seal manhole connector](image)

**Figure 14**: Positive seal manhole connector (Boot-Type Manhole Connectors, 2015)
The system of the seal has take-up clamps made up of stainless steel; they are fixed using the quick adjusting screws. Besides, this there are calibrated hydraulic installation tools that ultimately leads to powerful sealing of the seal system, as they have the power sleeve made of the stainless steel giving it strength. Since the whole system is already made up, it becomes easy to install the system in the manhole and the pipe at the time of the installation of the connection (Boot-Type Manhole Connectors, 2015).

High quality synthetic rubber is being used in the seal that gives it a high resistance to all the exertion and gives the seal a long life. This seal system is considered extra-long, they have the ability of double clamping, and this ability is available in all the sizes. The seal system has a power sleeve available in a single piece and it does not need any retightening or adjustment, but with time, the rubber loses its elastic ability and fails. The power sleeve used in the system eventually fails with the failing rubber and leads to the failure of the connection. The steel of the power sleeve corrodes and eventually cuts the rubber of the seal leading to the failure of the system (Boot-Type Manhole Connectors, 2015).

2.5 Compression type manhole connectors

The compression manhole connector uses the compression characteristics of the connecting seal to create a sealed connection. The pipe is pushed into the manhole and the seal is compressed around the pipe to create the connection. They are known as jab joints (Compression type manhole connectors, 2015).
2.5.1 Econoseal manhole connector

Econoseal Manhole Connector is a cast in manhole connector that is known for its easy installation and its excellent performance in sealing the manhole and pipe joints. The good thing with this seal is that while the manhole is poured, the key lock is created at the cored opening for the connection and the seal gasket easily sets into the key lock making the installation easy. This system provides a flexible watertight seal and it comes in the diameter range of 4 inch to 15 inch. One important feature for this system is that the mandrel is made of single piece and it is easy to remove it from the casting. This seal provides vacuum resistance and this system passes all the ASTM standards (Compression type manhole connectors, 2015).

![Econoseal manhole connector](image)

**Figure 15: Econoseal manhole connector**
*(Compression type manhole connectors, 2015)*

The process of the installation is fast and easy. First, a key lock installed into the manhole during the manhole pouring, and then the rubber seal is attached to it. When the manhole comes to the site, it is ready so that the pipe can be installed into it. The pipe is lubricated and beveled, it is then inserted into the manhole and by the compressive force of the rubber seal, the connection becomes watertight. Since there is no need to dry anything, it can be covered by the soil in no time. As the
A seal system is installed into the manhole at the time of the pouring it makes the system fast to install. A minimum amount of force has to be applied to push the pipe inside the manhole, which seal the system to make it watertight. The casting form can be easily replaced once it gets damaged (Compression type manhole connectors, 2015).

### 2.5.2 Kwik seal manhole connector

The kwik-seal-manhole-connectors are the compression type of the flexible manhole connectors. They are common and simple seals made up of rubber to create the watertight set up based on their property of compression. These are known for their precise setting and accuracy. They are easily set into a cast or the cored openings and the pipe is then inserted into the manhole to create the seal.

![Figure 16: Kwik seal Manhole Connector](Compression type manhole connectors, 2015)
The process of installing the seal gasket is simple since the rubber seal gasket is fixed on the cored opening of the manhole. Then, the pipe is beveled and lubricated at the end, which is inserted into the connection. Difference of the outer diameter of the pipe and the inner diameter of the seal gasket is the cause for compression. Because of the difference in the diameter, the pipe is fixed into the seal gasket at the manhole opening, thus installing the seal. The installation is easy, it does not need any tool to install the system and it uses less labor force. This seal system is available in most of the common sizes of the hole in the manhole, thus making it easily available for different connection (Compression type manhole connectors, 2015).

2.5.3 Kwik seal ST for storm

The Kwik seal ST for storm is used in storm sewers with high fluid pressure. The seal is set in the manhole pipe opening and the pipe is pushed into it. As a result, the gasket is deformed and compresses around the pipe, thus creating a watertight seal. This system eliminates the requirement of grouting the pipe into the storm water manhole. This system can be used in two types of cast and the cored holes, as the installation is relatively faster and easier as compared to the other seals. This seal exceeds all the required ASTM standards (Compression type manhole connectors, 2015).

Like the other compression seal connectors, this seal system is installed into the manhole. Then, the pipe to be inserted into the manhole is beveled and lubricated. This is done at the end of the pipe, which is to go inside the manhole. Since there is a difference in the outer diameter of the pipe and the inner diameter of the manhole seal, once the pipe is inserted into the connection, it creates a watertight seal by the forces of the compression. In this way, the system is installed. This seal system is effective in handling the problem of the differential settlement and it has been found that
it fails the least in the case of the differential settlement (Compression type manhole connectors, 2015).

Figure 17: Kwik seal ST for storm (Compression type manhole connectors, 2015)

2.6 External factors leading to the Seal failure

There are mainly two factors that cause seal failure. They are the external factors and the internal factors. The external factors are caused due to the external forces and the internal factors are caused due to the internal failure in the seals.

2.6.1 Changing climate

The changing climate alters the temperature and it causes many problems in the manhole and the pipe joints. Since the changing climate leads to varied expansion and contraction of the joint, it leads to cracking and breaking of the manhole connector material causing the leakage and the damage. It gives clues about the stress bearing capacity of the material that has to be used in the manhole and the pipe connection. Mortar is reinforced with fiber in the mix to provide some flexibility in the manhole and pipe connections. It is just to improve its elastic strength, so that it
can bear the stress and the tension and should not crack (Identifying Problems and Solutions to Leaky Manholes, 2015).

2.6.2 Overburden pressure

Sometimes, the back fill material over the pipe and the manhole connection creates a huge overburden pressure. This mainly happens when some structure is created over the pipeline or close to the pipeline. The pipe connections are only meant to handle a limited amount of pressure and in the presence of quite large pressure, the overburdened seal system fails.

2.6.3 High flow velocity in the pipeline

The high flow velocity and the pressure created because of this are many times the main reason of the failure of the manhole connector. Sometimes, during flooding and during heavy rain the flow volume inside the pipelines increases leading to pipes failure at the joint. The external climatic factors play a major role for the damage of the manhole connector, as the pipes are meant to handle a fixed amount of flow velocity. Sometimes the flexible pipe bursts and disrupts the pipeline (Management, 2009).

2.6.4 Imprecise manhole construction

The imprecise dimension of the manhole is one of the reason for the failure of the seals. However, the seal gaskets are produced with high precision, but the manholes are constructed by pouring of the concrete. Whenever the cast opening in the manhole is not constructed perfectly, due to pouring defects or impurities in the mortar or installation defects, it creates difference in dimension of the seal and the groove in the manhole. Therefore, it is important that the manhole and the pipe need to be precise in dimension for the successful working of the connecting seal.
2.6.5 Explosive decompression failure

When the pressure inside the pipeline is high and outside the pressure is low, then the gas penetrates into the rubber of the seal gasket and creates blisters and ruptures as the gas escapes. The gas is trapped into the rubber micro pore and it expands to match the outside pressure and in this process damages the rubber gasket (BHR Group Limited, 2006).

![Figure 18: Explosive decompression failure](BHR Group Limited, 2006)

2.6.6 Differential settlement

The problem of the differential settlement also plays an important role in the failure of the seals at the manhole to the pipe connection. Because of the differential settlement, the pipe at the manhole to pipe connection is tilted and then either the seal grout cracks or the seal undergoes elastic failure. Therefore, it is important to take care of the base soil while installing the pipe in the trenches.
2.6.7 High water table

The pipeline always faces an upward force in the areas of the high water table. On one hand, it destabilizes the pipe, and on the other, it creates dampness. In both the cases, the seal at the manhole to the pipe connection is damaged.

2.6.8 The corrosion of the concrete pipes

In the sewer pipe, the anaerobic bacteria ferment the sewage to produce the hydrogen sulfide gas. In presence of humidity, this hydrogen sulfide converts to sulfuric acid and this sulfuric acid reacts with cement of the concrete pipe and corrodes it. This damages the pipe and then it damages the connecting seal gasket (Manhole Corrosion, 2013).

2.6.9 The problem of Ozone cracking

Ozone cracking has been seen in presence of even small amounts of ozone gas, which creates cracks on the rubber gasket and leads to failure of the seal. Nitrile rubber is generally affected heavily by ozone cracking (Layer, 1990).

Figure 19: Ozone cracking (Layer, 1990)
2.6.10 Oxidation failure

Oxidation happens at the surface of the seal gasket and it creates the wear and tear in the seal gasket, which leads to the seal failure (Peters, 2015).

Figure 20: Oxidation of seal (Peters, 2015)
CHAPTER III
RESEARCH METHODOLOGY

3.1 Researching the various factors effecting manhole to pipe connection

The external factors and the internal factors lead to the seal failures. Both of these factors will be researched to find out the reasons of the failure and then proposing the various cost-effective methods to resolve them. The various external and internal factors researched are:

External Factors:

(i) Differential Settlement,

(ii) The problem of high water table,

(iii) External overburden pressure on the connection,

(iv) Natural calamities.

Internal Factors:

(i) Elasticity Failure,

(ii) Hardening of the seal gasket,

(iii) Swelling of the seal Gasket,

(iv) Oxidation Failure, Weathering and Ozone cracking,

(v) Explosion decompression failure,

(vi) Corrosion failure,

The design failure also leads to seal gasket damage, while the imperfection in the casting holes and making of the manhole poses serious problems. The installation failure happens due to faulty lubrication and friction cutting.
3.2 Finding out the reasons of the failure of the various seal material

This step includes the study of earlier research done on the reasons of the seal failure. This research will derive information from the manufacturers of the various seal materials since they are always being reported with the problems faced by their products. The research also includes talking to customers about their experiences, while using the various seals. It will also include their experiences about the various reasons of the failure of the seal materials. By their experiences, we will be deriving out the lifespan of the various seals.

3.3 Finding out the improvements needed in the seal materials

Once we are able to know the reasons of the failure of the seal materials, it would become easy to rectify the problems being faced by the seal materials. It has been found that the failure of the seal materials at the manhole to the pipe connection is being carried out by the external and the internal factors. All the improvements considered for the seal materials have to be cost-effective, so that the increase in the strength is better than the increase in the cost of the seal. Thus by this research a range of the price of the various types of the seal material will be proposed.

3.4 Developing a cost model

After adding the improvement cost, we will have the range of price of the various seal materials available in the market. We will then develop a cost model based on the concept of the equivalent annual cost. We will bring the prices of the various seals at one platform by using the concept of the equivalent annual cost, and the calculation will consider the life expectancy of the various seals.
CHAPTER IV
RESEARCH FINDINGS

4.1 Traditional seal system

4.1.1 Burlap with Mortar

When burlap with mortar seal is created by using the mixture of the Portland cement, sand and water, it always creates a very weak seal. If this mortar combination is not adapted to the burlap, it cracks easily and eventually the ingredients are separated from the burlap in the form of the powder. Even if the elasticity of the mixture is increased by mixing the latex paint, the system still does not work well and the burlap seal fails.

If plastic cement is used to improve the quality of the burlap with mortar seal, it works well in the site as a seal. The plastic cement contains the clay and some sort of plasticizers. Generally, two units of sand are mixed with one unit of the plastic cement. It works very well in the seal system, but it takes a bit longer to dry up. When the casting plaster is used in the burlap with mortar seal, it has been found out that the combination leads to a seal material that is very vulnerable to the damp condition. The seal is not weatherproof and it fails most of the time.

The best combination for the burlap with mortar seal is created, when the rapid set not shrinking grout is used on the burlap with latex concrete binder. This seal system has high elastic quality as well as high wear and tear strength. It sets easily and just in span of few days, it regains most of its strength. The advantage of this seal system is that it can set well in the underwater situation as well as it has been found out to be durable in the wet conditions. With all these qualities, it has been found out to be economical.
4.1.2 Mortar mixed with biological fiber

When the fiber mixed mortar seal is created by using the mixture of the Portland cement, the sand and water, it always creates a weak seal. This mortar combination is not adapted to the fiber and its cracks very easily. However, when the casting plaster is used in the fiber mixed mortar, the combination leads to a seal material that is vulnerable to damp conditions. The seal is not weatherproof and it fails. The best combination for the fiber mixed mortar is created, when the rapid set not shrinking grout is used on the burlap with latex concrete binder. This seal system develops as a strong seal after it dries and at the same time, it shows high elastic quality showing good resistance to stress.

4.1.3 Mortar mixed with fiberglass

An effective combination for the fiberglass and mortar mixture is created, when the rapid set not shrinking grout is mixed with lime and calcium stearate and then fiberglass is mixed to this mixture. Calcium stearate acts as the internal lubricant in this case, making the fiberglass to blend well with the cement. As the seal mainly fails due to the faulty installation, it is important to keep the installation process in check. Giving the installation some time and saving the joint from rain, sunlight and wind by covering the structure, helps the seal to set properly and gain strength.

4.2 Nitrile Seals

4.2.1 Nitrile seal gasket

The installation failure is common in the Nitrile seal gasket. In lack of right lubrication and due to imperfect manhole dimension, the seal gasket is cuts at the time of the installation. Using parker PTFE super O lube as high quality lubricant works well in improving the lubrication during the
installation. It leads to smooth installation giving the seal life; it is economical too. As this seal also fails due to the imperfection in the dimension of the manhole structure, using epoxy grout as Laticrete spectral lock will negate chances of seal failure due to imperfect manhole dimension. Breaking the sharp edges of the grooves of the manhole can also save the seal from installation failure.

4.2.2 Nitrile pre lubricated pipe gasket

This seal is used for concrete manhole and pipe system and it is made of synthetic nitrile butadiene rubber. They are fixed on the pipe by internal lubricants, which fail with time. Therefore, using a good lubricant like Devcon flexen primer increases the life of the seal system. At the lower temperature, the rubber gasket becomes brittle creating the need to use lubrication and epoxy grouting. It is effective to keep checking the hardness of the pipe gasket system in every 12 months.

Figure 21: Parker super o lube lubricant (hallowell, 2015)
4.2.3 Nitrile water stop

They are mainly applied over the cracks to cover-up the infiltration in the cementitious grout connections. Using the epoxy grout instead of the cementitious grout actually improves the life of the seals. Since they are applied over the grout, quality of the grout becomes important factor.

4.3 Cast-a-seal

4.3.1 Cast-a-seal 12-08 seal system

The accelerated aging leads to the compression failure and the system needs to be checked regularly to confirm its wellbeing. As per the research, adding 2-3% of Nano silica improves the compressive strength of the system. The steel clips used in the system usually fail and face corrosion, while it has been found out that nylon polymer clips work well in this case. The seal gasket is found to absorb water and so swelling becomes a main reason for the failure of the seal
system. However, adding asphalt at the time of the vulcanization improves resistance of the seal gasket against the dampness.

4.3.2 Cast-a-seal 802 connectors

They are flexible seals that are used for pipe diameter greater than 18 inches. From ASTM testing data, they have the tensile strength of 2100 PSI, while 1200 PSI is only needed. They have steel ring mandrel and which corrodes. It has been found that using fluoropolymer coating over the surface of the steel mandrel increases the life of the mandrel and the seal.

![Figure 23: Impact of fluoro polymer coating (Maudlin, 2015)](image)

4.3.3 Cast a seal 964 system

They are an efficient system of seals that can be used both an efficient system of seals that can be used both in manhole and the straight wall system. They have casting mandrel, which makes the installation easy. They have dual step fixing and they can accommodate all pipes with diameter ranging from 107-175 mm. The result shows that the compression strength of the seal decreases with time, so it is important to improve the compression quality and this has to be done by adding
2-3% of Nano silica to the rubber gasket at the time of the vulcanization. It also starts absorbing water with time, so adding asphalt at the time of vulcanization improves its water resisting ability.

4.4 Boot type manhole connector

4.4.1 Direct drive manhole connector

They are the premium type of the manhole connector available in the market. It has been found to be corrosion resistant and has a long life. It has ADS pipe adapter between the pipe and the seal and this increases its life. However, it fails due to the failing of the rubber gasket, which loses its elastic strength. From the research, it has been found that the compressive strength is increased by adding 2-3% of Nano silica while the tensile strength is increased by adding recycled rubber powder. This increases the price by only 3 to 5% and results into 20 to 30 % increase in the life of the seal.

![Figure 24: ADS pipe adapter (Seal, 2008)](image-url)
4.4.2 Nylo drive manhole connector

These manhole connectors have the same structure like the direct drive manhole connectors. However, they have a power sleeve made of nylon polymer with stainless steel inserted inside it. They are chemically resistant and very durable. The study shows that with time they lose their elastic strength and become brittle. However, it can be checked by adding aromatic alcohol TA 661 to the rubber at the time of the vulcanization. They also lose elastic strength with time, so the compressive strength of the seal system can be improved by adding 2 to 3% of Nano silica to the rubber, while the tensile strength of the seal is increased by adding recycled rubber powder.

4.4.3 Positive seal manhole connector

It is a high power and flexible manhole connector with a long life. However, with time, the rubber gets weaker and the stainless steel power sleeve cuts the rubber leading to failure, hence design change in the power sleeve is needed. The stainless steel should have to be replaced by nylon polymer to avoid sharp edges. This will increase price by 5 to 7%, but it will increase life by almost 20%. The compressive strength of the rubber is improved by adding 2-3% Nano silica and the tensile strength of the rubber is improved by adding recycled rubber powder.

4.5 Compression type manhole connector

4.5.1 Econoseal manhole connector

The seal setup is fixed to the manhole at the time of the pouring of the manhole structure. This quality reduces the chances of the seal failure due to the imperfect dimension of the manhole. With aging the compressive ability of the seal gasket decreases, but the use of the epoxy grout at the connecting spot increases the life of the seal. The compressive strength of the rubber is improved
by adding 2-3% of the Nano silica at the time of the manufacturing. As per the research, the use of the asphalt rubber in the seal gasket will reduce the scope of the water absorption in the rubber and it will give the seal a longer life.

4.5.2 Kwik seal manhole connector

The compressive strength of the rubber decreases with the time and the strength of the seal decreases with time. Hence, with time the seal fails leading to loss of the watertight ability. In the damp condition, the rubber absorbs the water, swells up and fails. It is required to improve the rubber quality and apply epoxy grout at connection of the pipe and the seal. Adding 2-3% of Nano silica to the rubber increases the compressive strength of the rubber and by adding the recycled rubber powder to the rubber, the tensile strength of the rubber is increased. Addition of the asphalt to the rubber decreases the water absorption ability of the rubber.

4.5.3 Kwik seal ST for the storm

This sealing system is well versed in handling piping with storm water. Frequent check and replacement of the seal system is needed as with time it loses flexibility and dries to become brittle. Addition of the aromatic alcohol TA661 at the time of the vulcanization improves the flexibility. However, addition of the recycled rubber powder in the rubber improves the tensile quality of the seal gasket. While addition of the 2-3% Nano silica in the rubber gasket leads to the improved compressive quality of the seal material, mixing of the asphalt to the rubber gasket leads to the reduction in the water absorption.
4.6 The imperfect manhole

The manholes are made by pouring of the concrete and the impurities leads to the imperfection in their dimension. Since the rubber seals are perfect in dimension, this dimension difference leads to seal failure. It has been found out that covering the manhole connection with the grouts is a good solution. Epoxy grout has been found better than the cementitious grouts in life and performance. It increases the cost by 5-7% and performance by 40 to 60%. Laticrete spectra lock pro is among the best epoxy grout in the market, which is efficient and economical.

The epoxy grout has been found out to be highly chemically resistant and have good bond strength. However, this quality is not found with the cementitious grout. The epoxy grout takes more time to set in the grout joints than the cementitious grout. However, they are a bit more expensive than the cementitious grout and their cleaning is expensive. In addition, some of the epoxy grouts are
specifically made for the glass tiles and cannot be used with other systems. The epoxy grouts are high flow and high resistant epoxy resins that on dryness turns to a non-shrinking precision grout.

The epoxy grouts can withstand high dynamic load shock and that is one of the major qualities of the epoxy grouts, while the cementitious grouts take a lot of time for the setting and cannot handle shock. The epoxy grouts are applied at a rate of 2-4 dollars per square foot and the main type of the grout to be used is the Laticrete spectra lock pro.

4.7 Differential settlement

Due to the differential settlement the connection at the manhole and pipe connection is tilted, which leads to seal failures. It is needed to clean the base soil of the trench and clean it of frozen soil, debris, large stones and soil clumps. If it is found that the trench bottom has a low quality of soil and the problem cannot be solved, then it is needed to change the soil and fill the base with a better quality soil. It has been found out that doing chemical stabilization and re-compacting reduces the problem of differential settlement. Asphotac that are the asphalt based emulsion spray and Coherex that are the biodegradable petroleum resin emulsion are some chemical stabilizers that can be used for stabilization of soil.

If quality of the base soil is low, it is important to remove the problem causing impurities and do chemical stabilization after re-compacting the base since it causes soil stabilization. If the removal of the base soil is not possible, then as a counter, the length of the pipe can be reduced and a number of pipes can be connected to each other with the help of gaskets and that will be effective to counter the differential settlement tilting.
**4.8 High water Table**

The problem of high water table destabilizes the pipe and it creates extensive dampness. It has been found that using plastic sheeting and shoring at the base of the trenches avoids the groundwater seeping into the trenches. Draining out the water helps in keeping the trench dry at the time of the installation. However, after that chemical stabilization has to be done. The dampness leads to the swelling of the seal system and it fails. Therefore, water needs to be continuously removed at the time of installation of the pipe.

The draining process has to be monitored with precision since there is always the fear of the seepage of the fine soil particles during drainage. If the base soil is seeped out, voids are created and when they break, they weaken the trench base. So after draining, chemical stabilization of the trench base need to be done.

**4.9 Overburden pressure on the pipe**

The manhole to the pipe connection is meant to handle a limited amount of pressure. It is important to keep the overburden pressure in check. Otherwise, the extra pressure leads to the failure of the connection. Strong metal piping can handle the extra pressure, but they are expensive. It is needed to mark out all those areas, where the overburden pressure is going to rise over the pipe system. In those regions, the pipe system should be escorted by a reinforced concrete structure or the pipes used in those areas should be made up of strong metal material that can handle the extra pressure existing there.
4.10 Corrosion of the concrete pipes

The hydrogen sulfide production inside the sewage pipe leads to the formation of sulfuric acids that mixes with the humidity inside the pipe and corrodes the concrete pipes. The hydrogen sulfide is produced by anaerobic bacteria, which grows where there is no oxygen. Providing supply of oxygen in the pipeline impairs the production of the hydrogen sulfide in the pipelines, which has to be done through ventilating the pipe system. This problem can also be handled by providing the pipeline with steep gradient; this will not let the sewage to accumulate. However, adding calcium nitrate will stop production of the hydrogen sulfide in the pipe, thus negating production of sulfuric acid. Another way to deal with this corrosion problem is to use the corrosion resistant cements and they are as PVC, calcium aluminate cement and vitrified clay pipe.

4.11 Explosive decompression failure

The pressure difference inside and out of the pipe leads to the gas piercing into the micro-pores of the rubber and then expanding causing rubber blisters and the seal failure. The time of decompression can be increased, by increasing the shear modulus of the rubber seal materials. This can be done through strengthening the rubber gasket by increasing hardness up to the 80-95 durometer range. Nitrile has been considered resistant to the decompression and the addition of the nitrile at the time of the vulcanization boosts the seal.

4.12 Oxidation failure

This problem occurs at the surface of the rubber gasket and it leads to its wear and tear. It has been found that it is effective to apply anti-oxidation grease on the surface of the seal gasket, like the Gardner Bender. Another way to handle this problem is by creating a chemically resistant covering
over the rubber gasket, which is effective in reducing the chances of oxidation. The polythene covering over the rubber gasket will be cheap, effective and durable solution.

4.13 Ozone cracking

The problem of the ozone cracking has been found out to be important since very small traces of the ozone gas can cause the start of the process of the ozone cracking. It has been found out that the rubber seals made up of the nitrile rubber and the butyl rubber are very readily attacked by the ozone gas and it leads to the ozone cracking. It is effective to add anti-ozonant to the rubber before the vulcanization. Paraffin wax has been considered good and low cost anti-ozonant. However, the other common anti-ozonants that can be mixed in the rubber at vulcanization are the ethyle diurea and p-phenylenediamine. The other way is to use the ozone resistant rubber like the EPDM rubber.

4.14 Cost model calculations for the various seal types

The Equivalent Annual Cost concept can be used in finding the best seal material. The equivalent annual cost of a product may be defined as the yearly cost incurred in using a product for its lifetime. The equivalent annual cost can be calculated by the formula:

$$ E A C = \frac{N P V}{A_{t,r}} \text{, where } A_{t,r} = \frac{1 - \frac{1}{(1+r)^t}}{r} $$

The different terms in the formula are:

EAC = Equivalent annual cost

NPV = Net present value
\[ A_{t,r} = \text{Present value of annuity factor} \]

\[ r = \text{Cost of capital per year (\%)} \]

\[ t = \text{Life expectancy of the product (Years)} \]

The lower the equivalent annual cost of a material, it is considered economically better (Jones, 1982).

### 4.14.1 Conventional seals

After including the various improvements in the conventional seals and making it modified, it has been found out that the price of the modified conventional seals are in the range of $12 to $18 each. This price range includes the cost of labor for its installation (Construction, 2008). The life of the modified conventional seal is expected to be 10 years. This calculation has to be done for 100 such connections. The cost of the capital has been considered 2\% per year for the modified conventional seal system.

Calculating by putting the values in the formula of EAC

For conventional seals, \( EAC = \frac{\text{NPV}}{10} \)

The average price of the conventional seal is $15 each

\[ EAC = 15 \times \frac{100}{10} = \$150 \text{ yearly} \]

The minimum price of the conventional seal is $12 each

\[ EAC = 12 \times \frac{100}{10} = \$120 \text{ yearly} \]
The maximum price of the conventional seal is $18 each

EAC = 18 x 100/10 = $180 yearly

4.14.2 Nitrile Seals

After adding the various improvements in the Nitrile seals and modifying it, it has been found out that the price range of the Nitrile seal is in the range of $28 to $40 each. This price range includes the cost of labor for its installation. The life of the Nitrile seal is expected to be 25 years (Sealing Products for Oil and Chemical Resistance, 2015). This calculation has to be done for 100 such connections. The cost of the capital has been considered 2% per year for the nitrile seal system.

Calculating by putting the values in the formula of EAC

For nitrile seals EAC = NPV/20

The average price of the Nitrile seal is $34 each

EAC = 34 x 100/20 = $170 yearly

The minimum price of the nitrile seal is $28 each

EAC = 28 x 100/20 = $140 yearly

The maximum price of the nitrile seal is $40 each

EAC = 40 x 100/20 = $200 yearly
4.14.3 Compression type seals

After adding the various improvements in the compression type seals and making it modified it has been found out that the price of the compression type seals are in the range of $30 to $50. This price range includes the cost of labor for its installation. Life of the compression type seal is expected to be 25 years (Compression type manhole connectors, 2015). This calculation has to be done for 100 such connections. The cost of the capital has been considered 2% per year for the compression seals.

Calculating by putting the values in the formula of EAC

For compression seals, \( \text{EAC} = \frac{\text{NPV}}{20} \)

The average price of the compression type seal is $40 each

\[ \text{EAC} = 40 \times \frac{100}{20} = \$200 \text{ yearly} \]

The minimum price of the compression type seal is $30 each

\[ \text{EAC} = 30 \times \frac{100}{20} = \$150 \text{ yearly} \]

The maximum price of the compression type seal is $50 each

\[ \text{EAC} = 50 \times \frac{100}{20} = \$250 \text{ yearly} \]

4.14.4 Boot type seals

After adding the various improvements in the boot type seals and making it modified it has been found out that the price range of the boot type seals are in the range of $126 to $216. This price
range includes the cost of labor for its installation. The life of the boot type seal is expected to be 60 years (Boot-Type Manhole Connectors, 2015). This calculation has to be done for 100 such connections. The cost of the capital has been considered 1% per year for the boot type seals.

Calculating by putting the values in the formula of EAC

For boot type seals, \( EAC = \frac{NPV}{45} \)

The average price of the boot type seal is $171 each

\[ EAC = 171 \times 100/45 = 380 \text{ yearly} \]

The minimum price of the boot type seal is $126 each

\[ EAC = 126 \times 100/45 = 280 \text{ yearly} \]

The maximum price of the boot type seal is $216 each

\[ EAC = 216 \times 100/45 = 480 \text{ yearly} \]

4.14.5 Cast-a-seal manhole connector

After adding the various improvements in the Cast-a-seal manhole connector and making it modified it has been found out that the price of the cast-a-seal, manhole connectors are in the range of $60 to $80. This price range includes the cost of labor for its installation. The life of the cast-a-seal manhole connector is expected to be 40 years (Cast-A-Seal Pipe Connectors, 2015). This calculation has to be done for 100 such connections. The cost of the capital has been considered 1.5% per year for the cast-a-seal type seals.
Calculating by putting the values in the formula of EAC

For cast-a-seals seals, EAC = NPV/30

The average price of the cast-a-seal manhole connector is $70 each

EAC = 70 x 100/30 = $233.33 yearly

The minimum price of the cast-a-seal manhole connector is $60 each

EAC = 60 x 100/30 = $200 yearly

The maximum price of the cast-a-seal manhole connector is $80 each

EAC = 80 x 100/30 = $266.66 yearly
CHAPTER V

CONCLUSION & RECOMMENDATIONS

5.1 Summary of Results

This section summarizes the result of the cost model developed as a part of the research. The cost model has been created based on the equivalent annual cost of the various types of the seals. From the cost model, it has been found out that the traditional seal system have the least equivalent annual cost, which is $150 per year. This calculation has been done for 12-inch pipe seal system. Hundred seals have been considered at a time for calculation. It has been found that the range of the equivalent annual cost is varying from $120 to $180 per year. The range is varying since the fluctuation in the price of the seal system and the labor expenses put into the system has been considered. The price of traditional seal connection has been found out to be in the range of $12 to $18 each. This price range includes the increase in the price of the seal system due to the improvements.

The equivalent annual cost of the Nitrile seals has been found out to be $170 and the price range varies from $140 to $200. The price of nitrile seal has been found out to be in the range of $28 to $40 each. The equivalent annual cost for the compression seals has been found out to be $200 and the range of the cost varies from $150 to $250 yearly. The price of the compression seals has been found out to be in the range of $30 to $50 each. The equivalent annual cost of the cast-a-seal system has been found out to be $234 and the range of the cost varies from $200 to $266. The price of the cast-a-seal has been found out to be in the range of $60 to $80 each. After calculating the equivalent annual cost for the boot type system, the calculated amount comes to $380 and the range of the cost varies from $280 to $480 yearly.
The price of the boot type seal has been found out to be in the range of $126 to $216 each.

![Equivalen Annual Cost of Seals](chart.png)

**Figure 26: Cost model of the various seal types**

It has been found out that the use of rapid set not shrinking cement with the latex concrete binder increases the elastic property of the seal and improves its life. This has been found out to be applicable for mortar mixed with biological fiber and mortar mixed with fiberglass. It has been derived out that application of the epoxy grout on the connecting juncture of the pipe and the manhole is effective in increasing the life expectancy of the compression and the cast-a-seal being used. The use of the nylon polymers in the boot type seals are more effective than using the steel rings.
5.2 Conclusion

Based on the results derived out from the above graph, it has been found out that the modified conventional seals have the least equivalent annual cost among all the types of the seals available. Even though they have less life expectancy, still in the long run and after a number of reinstallation, they comes out to be economical. The upfront cost is less and in the long term the equivalent annual cost is the least. But the boot type seals which are the most technically advanced seals have been found out to be expensive as their equivalent annual cost is highest. The variation in the cost range has also found out to be high. The only positive part they have is the relatively longer life than others. However, the expenses related to the compression seals and the cast-a-seal are comparable.

The cost model proposed through this research includes the increase in the price of the seal materials due to the improvements in the seal system. The model also includes the labor cost of the replacement of the seal connections. This is the reason why the equivalent annual cost has been defined in the range.

The two main factors affecting the life of the seal materials are the external factors and the internal factors. With the research it has been concluded that the external factors need to be dealt by making changes to the external environment of the seal materials and doing the improvement increases the life of the seal at the manhole to the pipe connection. However, it leads to an increase in the cost of the process of the installation.
When we are dealing with the internal factors of the seal materials, it has been concluded that if we are able to improve the quality of the rubber gasket internally, it is going to influence the life of the seal material. Improving the tensile strength and the compressive strength of the rubber gasket will help in increasing the life of the seal materials. The improvement in the flexibility and the water absorption ability also has an improving impact on the life of the seal. Based on the research of the internal qualities of the rubber gasket, the various ways of the improvements of the seal gasket have been found out.

5.3 Recommendation for the future research

While doing the research on the cost-effective manhole to the pipe connection, there were few of the topics, which has a major scope for future research. They are as:

(i) The research on the cost-effective sealing for the earthquake resistant pipelines is going to be an important topic to research. Importance of the earthquake resistant pipe system is increasing and there is a good scope of research.

(ii) There is a need for the research into the seal failures caused due to the increased pressure in the pipelines due to the rain or flood. These causes the increased flow rate and the increased pressure, which leads to failure.

(iii) There is a need and scope of research for the plastic manhole system. They beat the problem of the imperfection of the manholes and corrosion of the manholes and pipes. The demand of the plastic manhole system is going to increase in the future.
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