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COST COMPARISON OF CEMENT CONCRETE AND POLYMER CONCRETE

MANHOLES IN SEWER SYSTEMS

By

Sayan Sakhakarmi

Bachelor of Engineering - Civil Engineering
Tribhuvan University, Nepal
2011

A thesis submitted in partial fulfillment
of the requirements for the

Master of Science – Construction Management

Department of Civil and Environmental Engineering and Construction
Howard R. Hughes College of Engineering
The Graduate College

University of Nevada, Las Vegas
December 2017

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Thesis Approval

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Cost Comparison of Cement Concrete and Polymer Concrete Manholes in Sewer Systems

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ABSTRACT

Cost Comparison of Cement Concrete and Polymer Concrete Manholes in Sewer Systems

By Sayan Sakhakarmi

Cement concrete manholes are generally used in sewer networks in the United States. However, these concrete manholes are highly vulnerable to chemical corrosion and require frequent maintenance and replacement. Polymer concrete manholes as a substitute to the cement concrete manholes in water and wastewater pipelines have proved to have longer service life and more resistance to various chemical corrosions than normal concrete manholes. Despite the benefits that polymer concrete manholes offer, the higher initial installation cost has been a barrier to its wide application in public works. This study has been conducted to compare the cost of cement concrete manholes and polymer concrete manholes installed in the city of Las Vegas to determine the cost-effective alternative based on incurred cost throughout service life. The cost information on installation and rehabilitation of manholes were collected from the Clark County Water Reclamation District, the public entity responsible for construction and maintenance of sewer networks in the city of Las Vegas. The scope of this study was limited to the comparison between installation cost and rehabilitation cost of cement concrete manholes, comparison of installation costs between cement concrete and polymer concrete manholes, and comparison of installation and rehabilitation costs between cement concrete and polymer concrete manholes of different diameters. The results showed that the rehabilitation cost was significantly lower than the installation cost of 48-inch diameter cement concrete manholes. However, in case of 60-inch and 72-inch cement concrete manholes, the rehabilitation cost and installation cost were not significantly different. The installation cost of polymer concrete

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manholes was found significantly higher than that of cement concrete manholes. However, the installation and rehabilitation cost of polymer concrete manholes with a service life of 50 years and cement concrete manholes with a service life of 23 years were not significantly different. Hence, the cost comparisons indicated that the use of polymer concrete manholes is cost-effective in the long term compared to the traditional concrete manholes. The study suggests the use of polymer concrete manholes in sewer network despite the higher initial installation cost.

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المنارة للاستشارات
www.manaraa.com

TABLE OF CONTENTS

المنارة للاستشارات

www.manaraa.com

المنارة للاستشارات
www.manaraa.com

www.manaraa.com

LIST OF TABLES

المنارة للاستشارات

www.manaraa.com

المنارة للاستشارات
www.manaraa.com

LIST OF FIGURES

المنارة للاستشارات

www.manaraa.com

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www.manaraa.com

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CHAPTER 1: INTRODUCTION

1.1 Background

The sewer system in the United States consists of cement concrete manholes. However, these manholes are highly vulnerable to chemical corrosion, mainly due to Hydrogen Sulfide (H_2S) generated in the sewer systems (Hughes, 1997; Kienow & Kienow, 1991; USEPA, 1991). The corrosion causes failure of the cement concrete manholes, and these manholes require frequent maintenance/rehabilitation work to prevent it from failing. Various rehabilitation methods are applied to maintain the degraded manhole structures, such as chemical grouting, coating systems, miscellaneous spot repairs, cast-in-place structural relining of a manhole, and corrosion protection due to hydrogen sulfide (Hughes, 1997). The use of these rehabilitation methods throughout the service life of concrete manholes increases the overall costs of operating these manholes. Further, the closure of roads and generation of foul gas during maintenance and replacement period, affect the public life as well.

The requirement of expensive rehabilitation measures in addition to the shorter service life of cement concrete manholes has revealed the need for alternatives of these concrete manholes that have longer service life and are cost-effective. The United States Environmental Protection Agency (USEPA) has also focused on the use of emerging and novel technologies for more sustainable infrastructures (Sterling, Wang, & Morrison, 2009). The USEPA report suggested the use of geopolymers as a potential technology that would result in a more durable, reliable and more sustainable sewer network. Further, the geopolymers are environment-friendly, more corrosion resistant and stronger than the cement concrete.

Recently, the polymer concrete manholes, which uses fiberglass as a reinforcement instead of regular steel reinforcement, are used as a substitute for the cement concrete manholes. The

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polymer concrete manholes have a longer service life, a minimum of 50 years (Armorock, 2014a; Lang, 2005; LeBlanc, 2007) and more resistance to various chemical corrosion (Capuano, 1987) than cement concrete manholes (Armorock, 2014a; USCPS, 2010). Moreover, the use of polymer concrete manholes requires only one-time installation cost during its service life of 50 years while the use of cement concrete manholes incur regular maintenance costs as well as replacement costs in addition to the initial installation cost for the same period of 50 years. The 2017 Wastewater Infrastructure Report Card indicated that the expenses on operation and maintenance in the wastewater sector are approximately 50% of the total expenses (ASCE Foundation, 2017).

Considering the benefits of installing polymer concrete manholes, it has been widely used in water and wastewater pipelines, and the Clark County Water Reclamation District (CCWRD), the public entity responsible for constructing sewer pipelines in the City of Las Vegas, has also started using polymer concrete manholes instead of cement concrete manholes since 2009. The polymer concrete manholes were first used by CCWRD in the 661 Rehabilitation Project in Las Vegas (Armorock, 2014b). The project consisted of approximately 181 manholes to be either replaced or rehabilitated, out of which, 88 manholes were scheduled for lining while the remaining were planned to be replaced with new ones. After evaluating the polymer concrete manhole for over a year, CCWRD determined it to be a superior alternative product with a corrosion warranty of 50 years that is most suitable to deal with the frequent requirement of rehabilitation or replacement of existing manholes. As the original rehabilitation specification did not allow the use of polymer concrete manhole, CCWRD had to include an addendum in the contract to permit its use as an alternative product. The use of polymer concrete manholes in the project significantly reduced the installation time as it did not require any field curing time and application of corrosion

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protection coating like for the cast-in-place manholes. The spark tests and dolly pulls were also not required. It significantly shortened the traffic control duration as well.

However, the higher initial capital cost of installing polymer concrete manholes has been a barrier to its wider application in public works and CCWRD is unable to completely replace concrete manholes with polymer manholes despite all the benefits it offers. The cost of polymers ranges from 10 to 100 times that of the Portland cement (Fowler, 1999). Although the initial capital cost is higher for polymer concrete manholes, there is a possibility that these manholes are more cost-effective than the cement concrete manholes while considering all the associated costs throughout their service period. The concerned authorities have not yet conducted a cost comparison between these two manhole alternatives to determine the most cost-effective one for its application in the sewer networks. Therefore, the cost comparison of cement concrete manholes and polymer concrete manholes needs to be conducted to determine whether polymer concrete manholes are more cost-effective compared to cement concrete manholes. This research aims to assist the concerned public entities in selecting the best manhole alternative for their project, in terms of cost.

1.2 Research Objective

The main objective of this research is to determine the cost-effectiveness of using cement concrete and polymer concrete manholes based on the cost information available for manholes installed in the sewer system in the City of Las Vegas. This research aims to assist the public authorities responsible for maintaining sewer systems in selecting the best alternative manhole for sewer projects between the cement concrete and polymer concrete manholes in terms of cost.

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1.3 Research Hypotheses

Cement concrete manholes have a shorter service life, and it requires frequent maintenance/rehabilitation during its service period, while the polymer concrete manholes have a longer service life and more resistance to various chemical corrosion. Further, the polymer manholes do not require any maintenance as in the case of normal concrete manholes. Therefore, the research hypothesis of this study is that the installation and rehabilitation cost of polymer concrete manholes used in the sewer systems is lower than that of cement concrete manholes. The costs consist of the installation cost and rehabilitation cost of these two types of manholes. Installation cost is the cost of installing a new manhole, and rehabilitation cost is the cost of repair and maintenance of the existing manholes. The cost comparison is conducted for three different diameters of the manholes, i.e., 48-inch, 60-inch, and 72-inch. To prove research hypotheses, three separate statistical analyses will be conducted, one each for 48-inch, 60-inch, and 72-inch diameter manholes. Three research hypotheses are shown below:

Research Hypothesis 1: The installation and rehabilitation cost of 48-inch diameter polymer concrete manholes is significantly lower than that of 48-inch cement concrete manholes.

Research Hypothesis 2: The installation and rehabilitation cost of 60-inch diameter polymer concrete manholes is significantly lower than that of 60-inch cement concrete manholes.

Research Hypothesis 3: The installation and rehabilitation cost of 72-inch diameter polymer concrete manholes is significantly lower than that of 72-inch cement concrete manholes.

The research hypotheses are converted into null hypotheses for conducting statistical tests. Three null hypotheses related to these research hypotheses are shown below:

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Null Hypothesis 1: There is no significant difference in the cost of installation and rehabilitation between cement concrete and polymer concrete manholes of 48-inch diameter. Mathematically, it can be written as:

$$Installation\ and\ Rehabilitation\ Cost\ of\ Cement\ Concrete\ Manholes\ of\ 48-inch\ diameter$$
$$= Installation\ and\ Rehabilitation\ Cost\ of\ Polymer\ Concrete\ Manholes\ of\ 48-inch\ diameter$$

Null Hypothesis 2: There is no significant difference in the cost of installation and rehabilitation between cement concrete and polymer concrete manholes of 60-inch diameter. Mathematically, it can be written as:

$$Installation\ and\ Rehabilitation\ Cost\ of\ Cement\ Concrete\ Manholes\ of\ 60-inch\ diameter$$
$$= Installation\ and\ Rehabilitation\ Cost\ of\ Polymer\ Concrete\ Manholes\ of\ 60-inch\ diameter$$

Null Hypothesis 3: There is no significant difference in the cost of installation and rehabilitation between cement concrete and polymer concrete manholes of 72-inch diameter. Mathematically, it can be written as:

$$Installation\ and\ Rehabilitation\ Cost\ of\ Cement\ Concrete\ Manholes\ of\ 72-inch\ diameter$$
$$= Installation\ and\ Rehabilitation\ Cost\ of\ Polymer\ Concrete\ Manholes\ of\ 72-inch\ diameter$$

1.4 Research Scope and Limitation

The main scope of this research is to conduct a cost comparison between cement concrete and polymer concrete manholes installed in the sewer systems in the city of Las Vegas. The cost comparison includes the comparison between installation cost and rehabilitation cost of cement concrete manholes, and comparison of installation and rehabilitation cost between cement concrete and polymer concrete manholes.

The CCWRD record shows approximately 45,000 manholes installed in Las Vegas. However, the study is limited to the public sewer manholes that are all installed and managed by CCWRD. The manholes installed by the private parties are not included in this study. Also, the

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cost analysis is limited to the manholes for which the cost and other required information were accessible through CCWRD, i.e., around 5% of approximately 45,000 manholes in Las Vegas.

The service period of cement concrete manholes is determined based on the actual data available for replacement and rehabilitation. However, the polymer concrete manholes have not been replaced or rehabilitated in the sewer system in Las Vegas. Thus, the service period of the polymer concrete manhole is based on the manufacturer's warranty and previous research.

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CHAPTER 2: LITERATURE REVIEW

2.1 Corrosion in Cement Concrete Manholes

In the sewer network, the sulfide corrosion starts after sulfate in the sewage is converted into molecular hydrogen sulfide (H_2S), which is then released into the air and is deposited on the moist non-submerged structure of the sewer network (Kienow & Kienow, 1991; USEPA, 1991). Then, the aerobic bacteria of the genus *Thiobacillus* biologically converts H_2S into sulfuric acid (H_2SO_4) in the presence of moisture (Parker, 1947). The chemical corrosion of this nature due to hydrogen sulfide occurs only above the waterline in the sewer system, and the corrosion below the waterline is due to the acid attack caused by low pH sewage, i.e., due to the acidic nature of sewers (ASCE, 1988; Kienow & Kienow, 1991). Further, the H_2S gas directly reacts with the metal components of the manholes, which causes the corrosion of the fittings and appurtenances like the steps in the manholes. Thus, the chemical corrosion results in ultimate structural degradation of the cement concrete manhole structures (Parker, 1951) causing the manholes to collapse.

The Portland cement and steel reinforcement, which are the main construction materials used in cement concrete manholes, are both susceptible to chemical corrosion due to sulfuric acid. Besides, the use of either granitic aggregate or calcareous aggregate during construction significantly affects the rate of degradation of the concrete manhole structures (ASCE, 1988). The granitic aggregates are inert and are not affected by sulfuric acid. However, the calcareous aggregates are susceptible to chemical attack. While using the granitic aggregates, only the cement bonding materials are subjected to acid attack. This results in separation of the aggregate from the manhole structure wall that exposes the fresh cementitious material, and the corrosion of cement material extends deeper inside the structure wall increasing the rate of corrosion.

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However, both the cement and aggregate are subjected to acid attack while using the calcareous aggregate. Hence, for a given thickness of the structure wall, the time required to corrode the wall material is extended by a factor of up to 5 compared to the corrosion in case of granitic aggregate. Therefore, the use of calcareous aggregates increases the corrosion resistance of the cement concrete manhole structures.

The rate of corrosion is also affected by the amount of sulfide generated in the sewer (Hughes, 1997). Some of the factors causing an increase in sulfide production are high sewage temperatures, high biochemical-oxygen-demand sewage, a release of dissolved oxygen, flat sewer slopes with lower velocities, long detention times, increasing settling of organic solids and grit in the sewer invert, and surcharging gravity sewers (ASCE, 1988; Hughes, 1997; Kienow & Kienow, 1991; USEPA, 1991). Both the absence of moisture on the structure wall and the absence of oxygen in the sewer atmosphere prevent the formation of sulfuric acid, which also affects the rate of corrosion (ASCE, 1988). Further, the climatic condition is also one of the factors responsible for structural degradation of manholes. In cold places, cracks appear on the concrete structures due to freezing weather condition allowing deep penetration of sulfuric acid that increases the rate of degradation of the manhole structure.

The manholes are frequently inspected to assess their condition. The maximum inspection frequency of 10-15 years is used for general manhole condition while a shorter inspection frequency of 1-2 years is suggested for manholes with corrosion and other maintenance problems (Hughes, 1997). Based on the condition of the manholes, various rehabilitation measures are used such as chemical grouting, cementitious restoration, cast-in-place concrete restoration, polymer coatings/linings, cured-in-place lining, panel liners, FRP manhole inserts, mechanical seals, manhole frame and cover replacement, and replacement of

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manhole steps (NASSCO, 2013). Also, the cement concrete manholes are protected from sulfide corrosion through chemical control of sulfide generation, design of the sewer system hydraulics in order to avoid sulfide generation, using sacrificial concrete cover, use of calcareous aggregate, use of protective coating and use of various polymeric materials (ASCE, 1988). The HDPE and PVC liners and the plastic lined concrete structures are also excellent sulfide corrosion resistant sewer pipe materials (Kienow & Kienow, 1991).

MortezaNia and Othman (2012) conducted a life-cycle cost analysis of concrete pipes with different types of coatings, concrete pipes without coatings, and double wall corrugated high-density polyethylene (DWC-HDPE) pipes to determine the cost-effective pipe material for application in the sewer systems in Malaysia. The study included three types of coating - Epoxy (Ep), Polyurethane (PU), and the combination of epoxy and sodium silicate (Ep-SS). The diameter of pipes ranged from 375 mm to 1500 mm, and the cost information for pipes and the coating materials were based on the Malaysian market rates. The life of the pipes was assumed to be 25 years for the cost comparison between concrete pipes and concrete pipes with various coatings, and the life of the pipes was assumed to be 50 years for the cost comparison between concrete pipes with various coatings and DWC-HDPE pipes. The cost analysis conducted for the pipes of all sizes showed that the life-cycle costs per meter for concrete pipes with coatings were significantly lower than that for concrete pipes. However, the cost per meter of DWC-HDPE pipe was determined to be the same as the cost of concrete pipes with coatings, up to a size of 600 mm. For the pipes with a diameter greater than 600 mm, the life-cycle cost of the DWC-HDPE pipe was found to be significantly higher compared to the concrete pipes with coatings. Therefore, the authors recommended using DWC-HDPE pipes in sewer systems up to 600-mm in diameter and for the pipes with a diameter more than 600 mm, it was recommended to use

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concrete pipes with coatings. From the cost comparison, it was also observed that the cost of replacing the sewer network deteriorated pipes after the service life of 25 years with new concrete pipes is a minimum of 1.5 times more expensive than the cost of using coated pipes despite the higher initial price of the coated pipes. Further, the researchers also tested the three types of coatings to evaluate their action against acid attacks. The coatings were applied on the cylindrical concrete samples and then placed in the closed container with 10 % sulfuric acid for a period of 30 days. The performance of the coating materials was determined based on the dry weight difference of the coated sample before and after the test. It was found that the coating materials were able to protect the concrete sample from corrosion. The rate of corrosion of the concrete samples was significantly decreased, and the authors concluded that the coating materials are suitable to increase the service life of the concrete pipes.

2.2 Polymer Concrete

Polymer Concrete is a composite material that uses resins as the binding material and aggregate as a mineral filler (Capuano, 1987). Epoxy, vinyl ester, methacrylate, and saturated polyester are the major types of resins used in polymer concrete. Polymer concrete has higher resistance to chemical attacks and a greater strength compared to cement concrete. However, these characteristics of polymer concrete depend on the type of resins used (Capuano, 1987; Figovsky & Beilin, 2013). Various studies concluded that the polymer concrete has better properties compared to the cement concrete, which makes it more preferable to be used in the sewer networks. A test conducted to determine the applicability of 96 different coating and liner systems in the wastewater pipelines from 1983 to 2004 (Redner et al., 2004) found that the polymer concretes were unaffected by 10% sulfuric acid as well as 5% sodium hydroxide. A different study on the effect of temperature on the strength of polymer concrete concluded that

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both the compressive and flexural strengths of polymer concrete decreased with the increase in temperature from -10ºC to 60ºC (Rebeiz, 1995). However, the flexural strength was still found to be more than two times higher than that of ordinary Portland cement concrete. Similarly, the polymer concrete has higher modulus of rupture, higher ultimate compressive strain, and higher ductility compared to that of ordinary Portland cement concrete (Abdel-Fattah & El-Hawary, 1999). In different studies, the polymer concrete subjected to chemical degradation cycles displayed a reduction in flexural and compressive strengths (Gorninski, Dal Molin, & Kazmierczak, 2007; Reis, 2009). However, the remaining strength of the polymer concrete samples after exposure to the aggressive solutions was found to be higher than the strength of cement concrete that was not exposed to chemical attack. Reis (2010) conducted a similar type of study and concluded that the reduction in strength of the polymer concrete after exposure to different chemical solutions is lower compared to that in ordinary cement concrete.

Beeldens et al. (2001) conducted an investigation to improve the durability of concrete sewer pipes through polymer modification of the mortar and concrete. The type of polymer emulsion, curing conditions and polymer-cement ratio were the parameters considered during the polymer modification using eight different types of polymer emulsions (Styrene-acrylic ester, Polyacrylic, two types of Carboxylated styrene-butadiene and Styrene-butadiene with different minimum film-forming temperatures, Styrene-acrylic, and Vinyl copolymer). The experimental results displayed an increase in the flexural strength of the polymer-modified mortar while there is a decrease in porosity due to polymer modification except for Polyacrylic and Styrene-acrylic modified mortars compared to the mortar without polymer modification. Similarly, the 28-day compressive strength was found to be lower than that of the reference mortar. However, the study concluded that both flexural and compressive strengths are influenced by the curing

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condition as well. The compressive strength was determined to be higher in the case of the standard curing condition with 2-day moist and 5-day water curing. Further, the study of the influence of 0.5 % sulfuric acid solution on the samples showed that the rate of sulfate corrosion in polymer-modified concrete is much lower than that in non-modified concrete.

Hsu and Fowler (1985) studied the long-term deformation characteristics of methyl methacrylate-based polymer concrete under sustained loading and flexural behavior under cyclic loading. Cylindrical polymer concrete samples made of methyl methacrylate were subjected to different uniaxial compression stress-strength ratios. For each stress level, two samples were tested for a year to investigate creep behavior. From the test, it was determined that more than 20% of the final creep took place on the first day, and nearly 50% during the first five days. The creep in polymer concrete was determined to be approximately one to two times higher than that of Portland cement concrete. Similarly, plain polymer concrete beam samples were subjected to a 3 point load test to determine the flexural strength at different stress levels and stress ranges. It was determined that the increase in applied stress cause decrease in fatigue. Hristova and Bares (1987) studied the influence of the following composition parameters of the polymer concrete: type and chemical nature of the polymer binder, the filler/binder ratio in weight and the maximum grain size of the filler on creep. It was determined that the fine-grained polymer concrete has greater creep compliance than that containing coarser aggregate with grain size greater than 5 mm, both of them having the same resin binder. Similarly, for polymer concrete with different resin binders having different chemical nature and with nearly equal filler/binder ratio, the magnitudes and character of compliance are different. Also, for different filler/binder ratio, the creep compliance decreases with increase in the filler/binder ratio and the change in compliance is negligible beyond the ratio greater than 5.

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Ahn et al. (2009) conducted research to study the feasibility of using concrete polymer manholes to replace the existing cement concrete manholes with a development of a high strength polymer concrete and prepare a fundamental data for design. The main purpose of the experiment was to examine the physical properties of polymer concrete. The properties examined were specific gravity, absorption capacity, workability, strength, modulus of elasticity, and Poisson's ratio, which were required to develop a manhole. The polymer photo-manholes test specimen of three different sizes were fabricated for strength test of polyester resin concrete. The specific gravity and absorption capacity of three test specimens were determined according to ASTM C 127-01. The mean specific gravity was found to be 2.30 which is similar to that of cement concrete. Similarly, the mean absorption capacity of 0.39% was determined, which is much lower than that for cement concrete. This indicates much more improvement in waterproofing property of the material. The lower absorption capacity of the polymer concrete is advantageous for its use in manhole structures near subsurface water as there will be no leakage in polymer concrete like in cement concrete. Using Injection Method and Touching Method, the working life of the polymer concrete was determined, which is affected by the casting temperature and the amount of the accelerator and catalyst used. The test was conducted at 20^{0}C, and 60% humidity and the mean working life was determined to be 63 minutes for the three test specimens, which is sufficient enough to cast the concrete. Flow test was conducted to determine the workability of the mixture, and the mean flow value for the three tests was found to be 28.2%. The strength tests conducted in accordance with ASTM C 39-03 and C 580-02 showed that the mean 7-day compressive strength and the 7-day flexural strength for the five specimens of the three types of manholes were determined to be 127 MPa and 22 MPa respectively with a coefficient of variation of 7.2% and 6.3% respectively. The ratio of compressive and flexural

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strength was only 5.7, which is lower in comparison with the ratio of cement concrete (8.8 for 60 MPa compressive strength). This shows that the polymer concrete has a higher value of flexural strength in comparison to the cement concrete. The reason for the lower ratio is the use of a binder with high toughness. In accordance with ASTM C 469-02, the wire strain gauge method was used to determine the modulus of elasticity and the Poisson's ratio. The longitudinal and lateral strains were measured using 70 mm and 30 mm strain gauges respectively. The mean value for modulus of elasticity and Poisson's ratio were determined to be 2.8×10^4 MPa and 0.21 respectively, which in comparison to cement concrete with 70-90 MPa compressive strength shows that the modulus of elasticity value is much lower and the Poisson's ratio is significantly higher. Also, the comparison of stress and strain of both polymer concrete and cement concrete showed the higher strain of polymer concrete, indicating higher toughness of polymer concrete which is suitable for manhole structure. The researchers concluded that the high strength polymer concrete could be designed as required for the use in manholes that are superior in quality.

2.3 History of the use of Polymer Concrete

In the United States, the polymer concrete was initially introduced to produce building cladding as early as 1958 (Fowler, 1999). Since then, the polymer concrete has been widely used to produce floor tiles, sanitary wares, drains, underground boxes, manholes, acid tanks and cells, hazardous waste containment, tunnel lining, highway median barriers, shells for repairing machinery foundations, stay-in-place and tunnel forms, sleepers, and architectural moldings. Though the polymer concrete was initially used as a replacement for cement concrete, it was later used to replace metals as well. For example, it was used to replace cast iron for machine tools and bases due to its properties like high strength and stiffness-to-weight ratio, high

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damping properties, moldability and low thermal conductivity. The polymer pipe was first used in the form of a jacking pipe in the US in California in 1996 (Lang, 2005). Similarly, the polymer concrete manhole was first installed in the US in 2002 as a test manhole to replace a corroded cement concrete manhole in a force main system in Michigan.

2.4 Case Studies

LeBlanc (2007) conducted a case study in a rehabilitated Lansing, MI sewer line of Westside Interceptor Phase IV-C Project that involved replacement of 20 manholes damaged due to hydrogen sulfide corrosion. The damaged manholes were replaced with polymer concrete manholes, including a customized junction chamber fabricated by Amitech USA. It was designed in such a way that it could accommodate the connections between manholes and the pipe of various shapes and orientations. The replacement manholes were fabricated with a smaller outer dimension of 6 by 9 feet to accommodate it within the footprint of the old manholes, which was 10 feet in diameter. It helped to minimize the disruption as most of the replacement sites were in or adjacent to public streets. In addition to the faster installation, the use of polymer concrete manholes also provided long-term chemical resistance without any linings, coatings or cathodic protection. The replaced polymer concrete manholes are expected to have a minimum service life of 50 years.

The wastewater sewer system in downtown Austin initially used cast-in-place concrete (CIP) manholes, which had a severe corrosion problem (Dawson, 2017; Parsons, 2010; SAK, 2012). The rehabilitation of the corroded manholes was very difficult and expensive. So, PVC liner and other protective coatings were used inside the CIP manholes, which had better results. However, even a small defect in liner/coating or damage even after installation would be very problematic later. Learning from these past experience, polymer concrete manholes were

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selected to be used in the seven deep tunnel access manholes, 70 to 90 feet deep, along the 3.9-mile long gravity flow wastewater tunnel in Austin Downtown Wastewater Tunnel project. The base was cast using cast-in-place cement concrete with a protective coating. The use of polymer concrete manholes greatly reduced the construction effort and shortened the project schedule with no change in construction cost. The wastewater tunnel replaced a 50-year-old sewer system and is expected to have a service life of more than 100 years due to the high corrosion resistance property of the polymer concrete. Furthermore, it significantly reduced the maintenance and repair costs of the project resulting in huge savings over the lifetime of the wastewater system.

2.5 Cost Comparison

Bozkurt and Islamoğlu (2013) conducted a cost comparison of the manufacturing cost of cement-based and polymer-based concrete pipes used in Turkey. The manufacturing cost of both types of pipes included the cost of raw materials, labor costs, and overheads, as well as the beginning inventory cost. The service life of cement-based and polymer-based pipes were considered to be 15 years and 50 years respectively. For the cost comparison, the researchers selected nine sizes of polymer-based pipes with diameters ranging from 415 mm to 3974 mm and six sizes of cement-based pipes with diameters ranging from 150 mm to 600 mm. The unit prices of the raw materials used for both types of pipes were determined based on the market price. Besides the cost of raw material, other expenses for manufacturing like beginning inventory cost, labor cost, and manufacturing overhead and even the manufacturing conditions were assumed to be the same for both types of pipe. The cost comparison was conducted considering the length of pipes to be 1000m and the respective service lives of both types of pipes. While just considering the material cost, the annual cost of polymer-based pipe was determined to be about 120% greater than the cost of cement-based pipes. However, the annual

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cost of the polymer-based pipe was determined to be 2.5 times more economical than that of cement-based pipes while considering the total manufacturing process cost over the service life for each type of pipe. With the use of the polymer-based pipe, there is a reduction in repair and maintenance for the service life period. In the case of the cement-based pipes, it is repetitive and requires complete replacement as well while considering the service life of 50-years similar to the polymer-based pipe. Hence, the authors suggested using the polymer-based pipes to reduce the cost of repair and maintenance, lengthen service life, improve strength and for high corrosion resistance.

2.6 Summary of Literature Review

The review of the literature showed that the chemical corrosion is a major problem in the sewer networks causing structural degradation of cement concrete manholes. Polymer concrete manhole, which has better corrosion resistance and higher strength as demonstrated by various research, are a better substitute of the cement concrete manholes in the sewer networks. The case studies also showed that the use of polymer concrete manholes significantly decreased the installation duration and reduced the maintenance cost over the service life. The study on cost comparison of cement-based and polymer-based concrete pipes demonstrated that the polymer-based concrete pipes are more cost effective while considering the total manufacturing cost over the service life.

However, the literature review revealed that most of the research on polymer concrete are focused on their properties rather than the cost factor. A research was conducted to compare the cost of cement-based and polymer-based concrete pipes used in sewer networks. However, a study on cost comparison of cement concrete and polymer concrete manholes has not been conducted yet. Due to which, the public authorities are unable to justify the use of expensive

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polymer concrete manholes in sewer networks. Though the initial installation cost of the polymer concrete manhole is higher compared to the cement concrete manhole, the polymer concrete manhole has longer service life and higher corrosion resistance. Hence, an extensive study on cost comparison between these two types of manholes would assist the public authorities in selecting the use of cement concrete manholes or polymer concrete manholes in the public sewer projects.

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CHAPTER 3: RESEARCH METHODOLOGY

3.1 General Outline

This study on cost comparison between cement concrete and polymer concrete manholes involved five major steps. The first step was defining the objective and the scope of the study that has been discussed in chapter 1. Then, the next step was an extensive literature review, which has also been discussed in chapter 2. As the research involved cost comparison of cement concrete manholes and polymer concrete manholes, cost information on the manholes was required. So, the next step was to collect cost information on installation and maintenance/rehabilitation of both cement concrete and polymer concrete manholes. The data collection was followed by data analysis, and then finally, conclusions were made based on the cost analysis. The general outline of the research methodology is shown in the flowchart below:

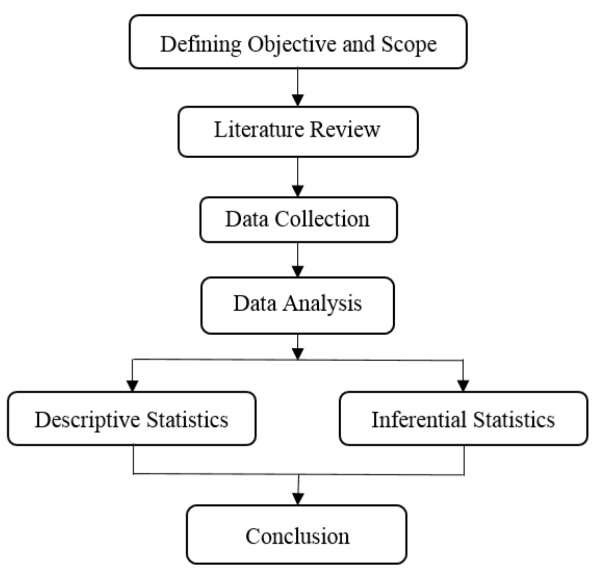

Fig. 1: General Outline of Research Methodology

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3.2 Data Collection

As the study was fully based on the cost comparison of the cement concrete and polymer concrete manholes, the data collection on cost information of those manholes was the major step of this study. After a series of correspondences and meeting with the Clark County Water Reclamation District (CCWRD) personnel, they agreed to give access to their database for cost data collection. Then, the required cost information, i.e., initial construction costs and maintenance costs for both cement concrete and polymer concrete manholes were collected from CCWRD.

CCWRD has a database called "ProjectView" with information on all projects on construction and maintenance/rehabilitation of sewer pipelines in the city of Las Vegas. Each project on the database consisted of complete project information including a complete set of contract documents, technical specification, and as-built drawings. However, the database consists of the project information completed since 2007 only. So, the data for construction costs were first exported from the database since that year. The exported data consisted of contract documents, specification, and as-built drawings for each project. The cost information for projects completed before 2007 had to be collected from hard-copy documents available in the archive. So, the required information for those projects before 2007 was collected from contract documents, specification, and as-built drawings in the form of photographs. The projects from 1977 to 2006 were found in the archive. The projects included both new construction and rehabilitation projects of manholes and sewer pipelines.

For each project, the cost information of manholes was determined from the bid schedule of the contract document. The bid schedule consisted of unit cost of manhole of different diameter, and mostly, they had different unit rates for manholes shorter than 12 feet and higher

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than 12 feet, and in some other cases, they had different rates for manholes shorter than 10 feet and higher than 10 feet. The unit cost of manhole included the cost of labor, equipment, material, and overhead required for excavation, installation, backfill, and any other activities necessary for completion of the work. The information extracted from bid document was the diameter of manholes, number of manholes, and the unit cost of each manhole. The information on unique manhole identification number, height, and diameter of individual manholes was not available in the bid document. Thus, as-built drawings were used to obtain other details of each manhole like:

- unique Manhole Identification number,
- diameter and height of individual manholes,
- construction date (completion date of the project), and
- construction and rehabilitation notes.

All the information collected from CCWRD were then entered into a Microsoft Excel spreadsheet. From the data, it was determined that the most common size of manholes used in the sewer system in Las Vegas were 48-inches, 60-inches, and 72-inches. However, a few manholes of 36-inches and 96-inches diameter were also determined during the data entry, but those manholes were excluded for cost analysis.

According to the officials from CCWRD, the first polymer manhole was installed in Las Vegas in 2009. However, according to the data, the first one was installed in 2015. It was found that only six projects out of the total 64 number of projects had polymer manholes installed.

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3.3 Data Analysis

3.3.1 General Arrangement of Data for Analysis

After all the information were entered into a spreadsheet using Microsoft Excel 2016, separate spreadsheets were prepared for cement concrete manholes and polymer concrete manholes. For both types of manholes, separate spreadsheets were prepared for newly constructed manholes, replaced manholes and rehabilitated manholes. Further, separate spreadsheets were prepared for 48-inch, 60-inch, and 72-inch diameter manholes. The unit costs of all manholes were then converted into cost per feet by dividing the unit cost by the height of the manhole. As the unit costs of manholes were obtained from the bid schedule of the projects constructed during different years from 1977 to 2017, the cost per feet of all manholes was then converted to the 2017 base cost using the construction cost indices from the Engineering News Record (ENR).

3.3.2 Comparison between Installation Cost and Rehabilitation Cost of Cement Concrete Manholes

The comparison between installation cost and rehabilitation cost of cement concrete manholes was conducted through descriptive and inferential statistical analyses for different diameters, using the statistical software called Statistical Package for the Social Sciences (SPSS).

3.3.3 Comparison of Installation Costs between Cement Concrete and Polymer Concrete Manholes

The comparison of installation costs between cement concrete and polymer concrete manholes was conducted through descriptive and inferential statistical analyses for different diameters separately using SPSS software.

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3.3.4 Comparison of Installation and Rehabilitation Costs between Cement Concrete and Polymer Concrete Manholes

3.3.4.1 Frequency of Replacement and Rehabilitation of Manholes

To calculate the frequency of replacement years of the cement concrete manholes, the unique Manhole Identification number of each replaced manhole was matched in the database containing newly installed manhole to find out when those particular manholes were first installed. Then, the average duration for replacement of concrete manholes was determined in years based on the replacement duration of all matched manholes.

After matching the newly installed manholes and replaced manholes to determine the average replacement frequency, all the newly installed and replaced manholes were further matched with the manholes from the sheet containing rehabilitated manholes to identify rehabilitation for each manhole. Based on this, the average duration of rehabilitation of cement concrete manholes was also determined.

However, in the case of polymer manholes, CCWRD had not replaced any of those manholes, and hence there was no record of any replacement. Therefore, the service life of the polymer concrete manholes was decided based on the literature from the previous research and the manufacturer's information (Armorock, 2014a; Bozkurt & Islamoğlu, 2013). The service life of polymer manholes was assumed to be 50 years. However, for comparison, two costs of polymer manholes were calculated based on a 50-year and 25-year period.

3.3.4.2 Comparison of the combined Costs of Installation and Rehabilitation

In the case of cement concrete manholes, there were records of rehabilitation as well that were considered for the cost analysis. The cost of rehabilitation of cement concrete manholes

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was added to the installation cost of the related cement concrete manholes, both at the base cost of 2017. However, in the case of polymer concrete manholes, it just included the installation cost per feet as they did not require any maintenance/rehabilitation. The combined costs of installation and rehabilitation were then dividing by the service life of each type of manholes to convert the costs in terms of annual cost. Finally, the descriptive and inferential statistical analyses were carried out to compare the installation and rehabilitation costs per feet per year of both types of manholes for different diameters separately using SPSS.

3.4 Descriptive Analysis

For each case of cost comparison between cement concrete and polymer concrete manholes, the descriptive statistics including mean, median, minimum, maximum, and standard deviation were calculated using SPSS to get general information of the samples.

3.5 Inferential Analysis

For each case of cost comparison, t-Tests for two samples with unequal variances were conducted to determine whether the two costs are significantly different from each other or not. However, the non-parametric test called Mann-Whitney U test was conducted in the case of cost comparison between cement concrete and polymer concrete manholes, due to the smaller sample size of polymer concrete manholes of 48-inch and 60-inch diameters.

3.6 Bonferroni Correction of Significance Value

The significance value (alpha) of 0.05 was considered for all the inferential analyses in this study. However, the statistical tests were conducted three times for different diameters in each case of cost comparison. The multiple statistical testing within each case causes a

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familywise error in the calculation of p-value (McDonald, 2014). Hence, Bonferroni correction is applied to the assumed critical alpha value to minimize the error rate. The corrected alpha value for the individual test is obtained by dividing the significance value by the number of tests. In this study, the corrected significance value would be $0.05/3 = 0.0167$. Thus, the individual tests with $p < 0.0167$ are only considered significant. The application of Bonferroni correction decreases the critical alpha value so that the probability of error is minimized.

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CHAPTER 4: DATA ANALYSIS AND RESULTS

4.1 Data Information

4.1.1 General Information of All Manholes and Cost Calculation

All the information on installation and rehabilitation of both cement concrete and polymer concrete manholes were extracted from a total of 64 projects completed from 1977 to 2017. From the data, it was determined that a total of 1166 cement concrete manholes of different diameters were installed in the city of Las Vegas since 1977. The installed cement concrete manholes included 18 manholes that were replaced as well. A total of 1045 cement concrete manholes were rehabilitated since 2006. However, out of a total 1145 newly installed manholes, only 92 manholes were rehabilitated. The cost information of only these 92 manholes was used out of the total 1045 rehabilitated concrete manholes for the purpose of the combined installation and rehabilitation cost comparison between cement concrete and polymer concrete manholes. The following table shows the number of manholes according to diameters:

Table 1: Breakdown of Number of Cement Concrete Manholes of each diameter

Diameter	48-inch	60-inch	72-inch	Total
Installed Manholes	351	454	343	1148
Replaced Manholes	2	6	10	18
Rehabilitated Manholes	376	496	173	1045
Rehabilitated Manholes considered in the combined installation and rehabilitation cost comparison	8	61	23	92

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The data for polymer concrete manholes showed that only 127 manholes were installed since 2015. Out of the total 64 projects, polymer concrete manholes were found in 6 projects only. As none of the polymer concrete manholes had been rehabilitated, the cost analysis only includes the installation cost of polymer manholes. The following table shows the number of polymer concrete manholes of different diameters:

Table 2: Breakdown of Number of Polymer Concrete Manholes of each diameter

Diameter	48-inch	60-inch	72-inch	Total
Installed Manholes	16	20	91	127

All the available installation and rehabilitation costs were then converted into the cost per feet by dividing the unit cost of manholes obtained from the bid schedule with the height of the manholes. As the manholes were constructed during different years from 1977 to 2017, the cost per feet of each manhole was then adjusted to the average base cost of 2017 using the Engineering News Record (ENR) construction cost indices. These adjusted base costs were the final cost data used for the further analysis.

Further, the cost comparison was divided into two parts as the cost information available for two types of manholes were from different durations. First, the cost comparisons were conducted using all available cost data, i.e., cost information of cement concrete manholes from 1977 to 2017 and polymer concrete manholes from 2015 to 2017. For more reliability of the analysis, then the cost comparison was conducted for the duration from 2015 to 2017 for both types of manholes.

4.1.2 Replacement and Rehabilitation Duration of Cement Concrete Manholes

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From the data available, it was found that the duration for replacement of 18 cement concrete manholes ranged from a minimum of 2 years to a maximum of 31 years with an average of 23.11 years. It was also found that the duration for rehabilitation of 92 cement concrete manholes ranged from a minimum of 4 years to a maximum of 36 years with an average of 23.27 years. The following table shows the percentage of rehabilitation of cement concrete manholes of different diameters:

Table 3: Percentage of Cement Concrete Manholes Rehabilitated

Diameter of Manholes	Total No. of Manholes	No. of Rehabilitated Manholes	% of Rehabilitation
72”	343	23	6.71%
60”	454	61	13.44%
48”	351	8	2.28%

The average duration of both replacement and rehabilitation of cement concrete manholes was determined to be approximately 23 years. Therefore, the average duration of 23 years was applied for annual installation and rehabilitation cost calculation of cement concrete manholes.

4.2 Descriptive Statistics

4.2.1 Comparison between Installation Cost and Rehabilitation Cost of Cement Concrete Manholes

The cost data for rehabilitation of cement concrete manholes was available from 2006 onwards only. For the comparison between installation cost and rehabilitation cost of cement concrete manholes, only the manholes installed from 2006 were considered. The sample size of installation costs and rehabilitation costs of the manholes were 725 and 1045 respectively. The

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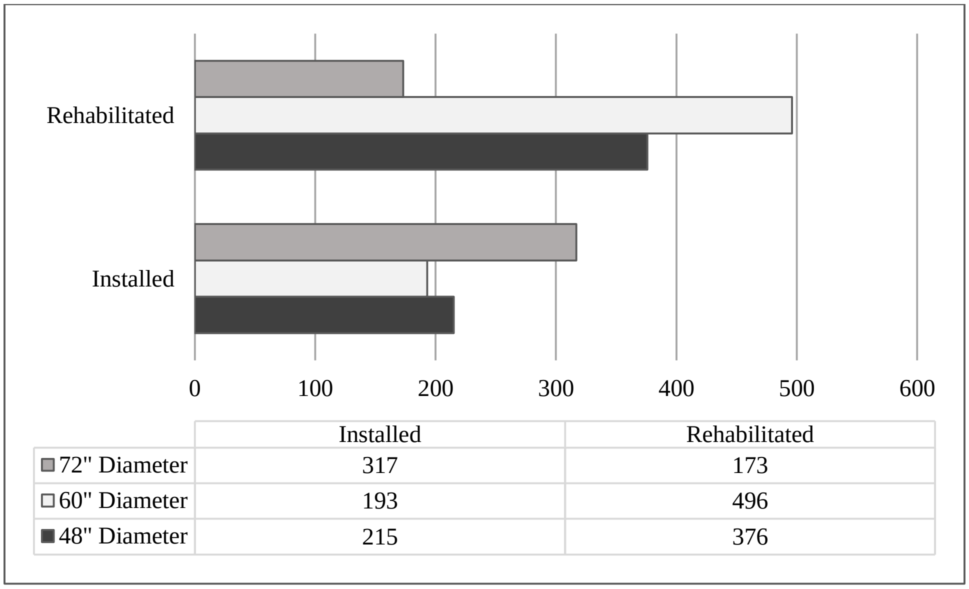
distribution of the number of different diameters of manholes are represented in the following figure:



	Installed	Rehabilitated
72" Diameter	317	173
60" Diameter	193	496
48" Diameter	215	376

Fig. 2: Number of Cement Concrete Manholes of different diameters for Comparison between Installation cost per feet and Rehabilitation cost per feet (2006-2017)

Further, the following charts show the descriptive statistics of the samples of installation cost per feet and rehabilitation cost per feet of cement concrete manholes separately.

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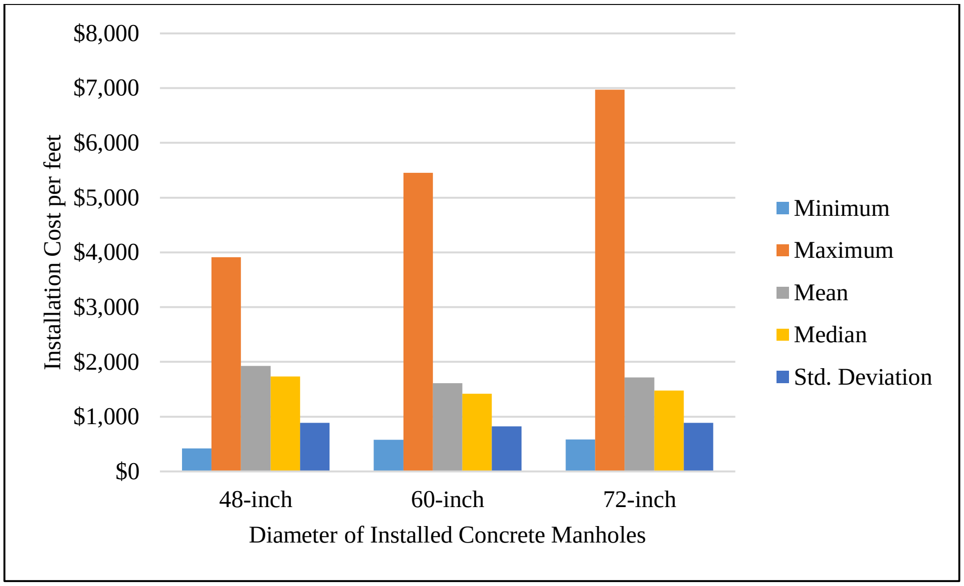

Fig. 3: Descriptive Statistics of Installation Cost per feet of Cement Concrete Manholes (2006-2017)

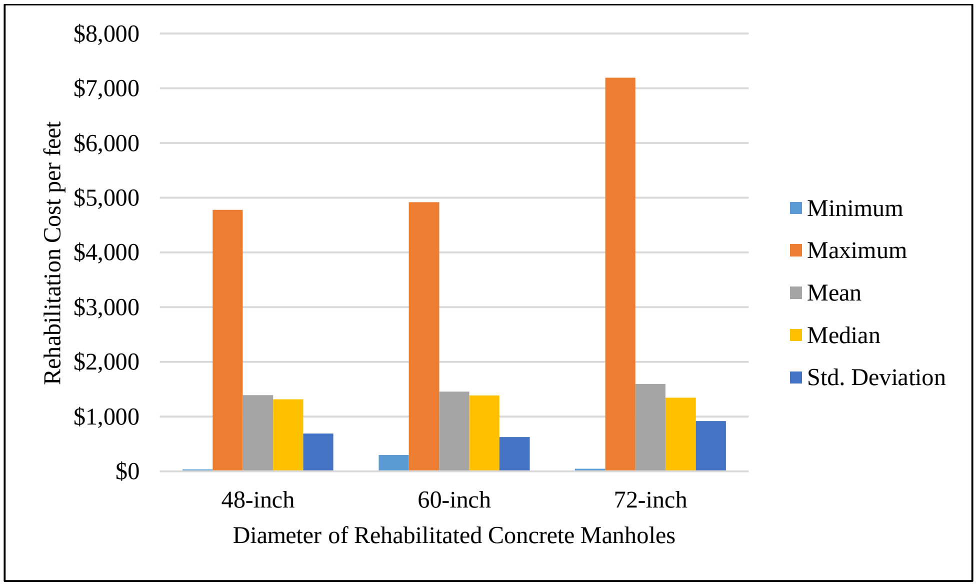

Fig. 4 Descriptive Statistics of Rehabilitation Cost per feet of Cement Concrete Manholes (2006-2017)

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The comparison of mean and median costs of installation and rehabilitation of cement concrete manholes of different diameters show that the rehabilitation costs are slightly lower than the installation costs. The comparison is shown in the figure below:

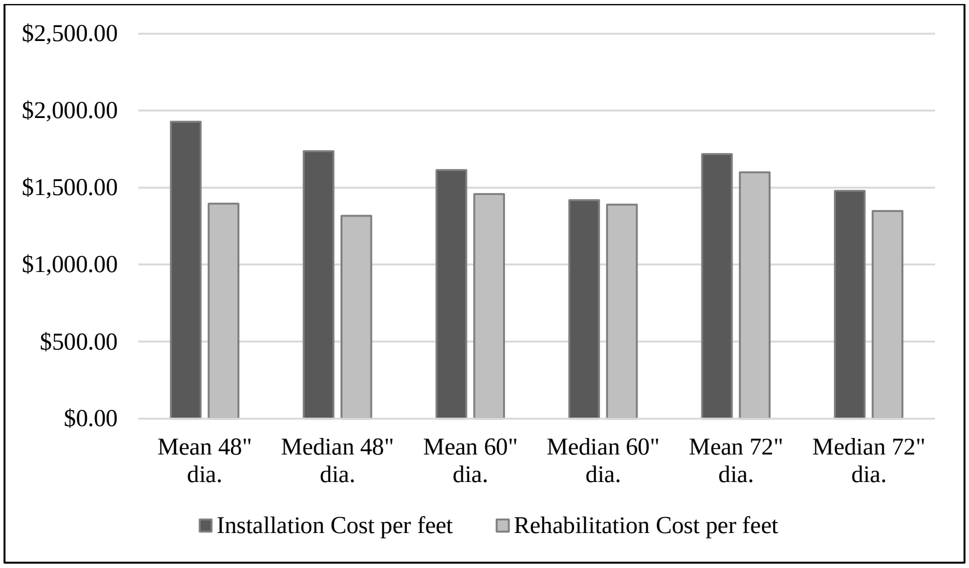

Fig. 5: Comparison between Installation Cost and Rehabilitation Cost (Mean and Median) of Cement Concrete Manholes (2006-2017)

4.2.2 Comparison of Installation Costs between Cement Concrete and Polymer Concrete Manholes

This section includes the comparison of installation costs between cement concrete and polymer concrete manholes.

4.2.2.1 From 1977 to 2017

For the comparison of installation costs per feet from 1977 to 2017, the sample size of cement concrete and polymer concrete manholes were 1166 and 127 respectively. The distribution of the number of different diameters of manholes are represented in the following figure:

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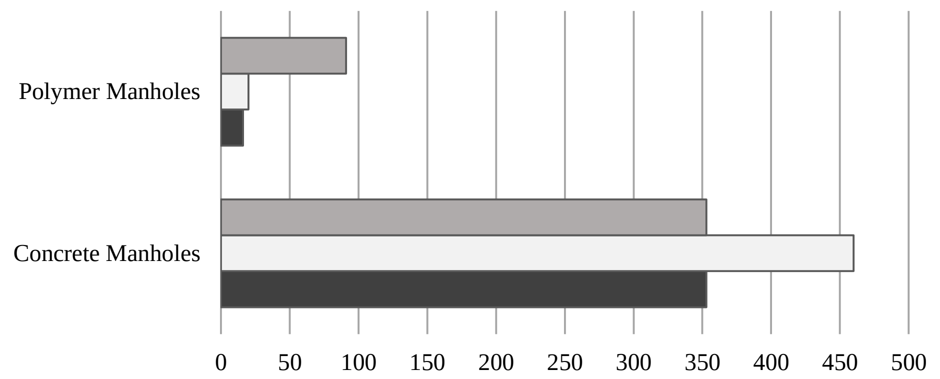

	Concrete Manholes	Polymer Manholes
72" Diameter	353	91
60" Diameter	460	20
48" Diameter	353	16

Fig. 6: Number of Cement Concrete and Polymer Concrete Manholes of different diameters for Comparison of Installation Cost per feet (1977-2017)

Further, the following charts show the descriptive statistics of both cement concrete and polymer concrete manholes. The descriptive statistics show a uniform increment of different statistics values of the installation cost per feet for both types of manholes.

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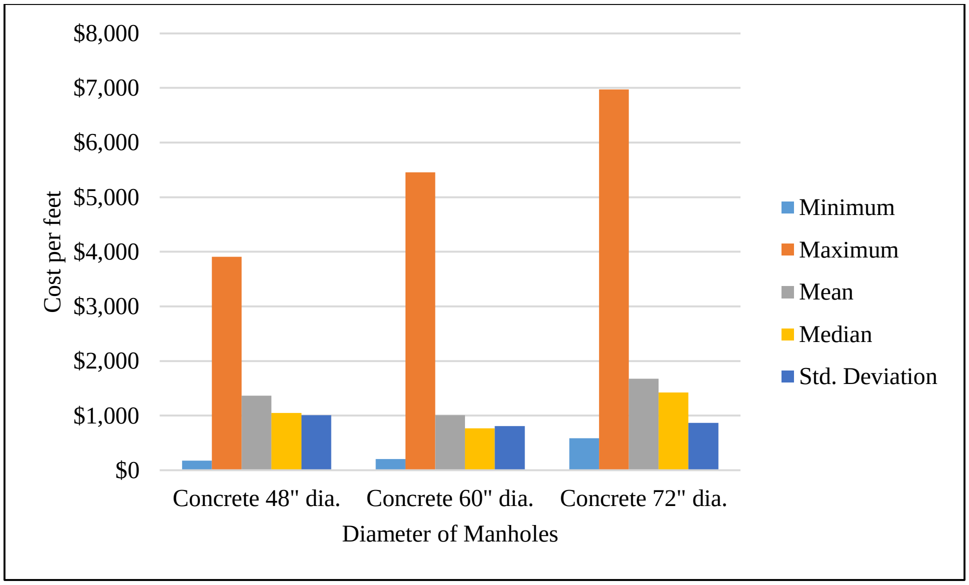

Fig. 7: Descriptive Statistics of Installation Cost per feet of Cement Concrete Manholes (1977-2017)

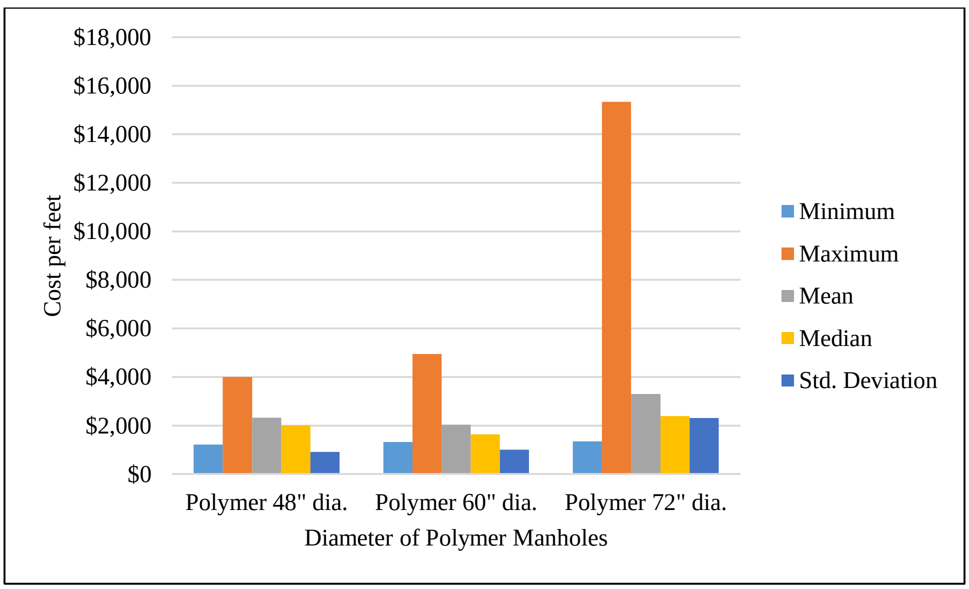

Fig. 8: Descriptive Statistics of Installation Cost per feet of Polymer Concrete Manholes (1977-2017)

The comparison of mean and median values of the installation costs per feet between the cement concrete and polymer concrete manholes of different diameters, for the duration 1977-

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2017, show the higher cost of polymer concrete manholes. The comparison is shown in the figure below:

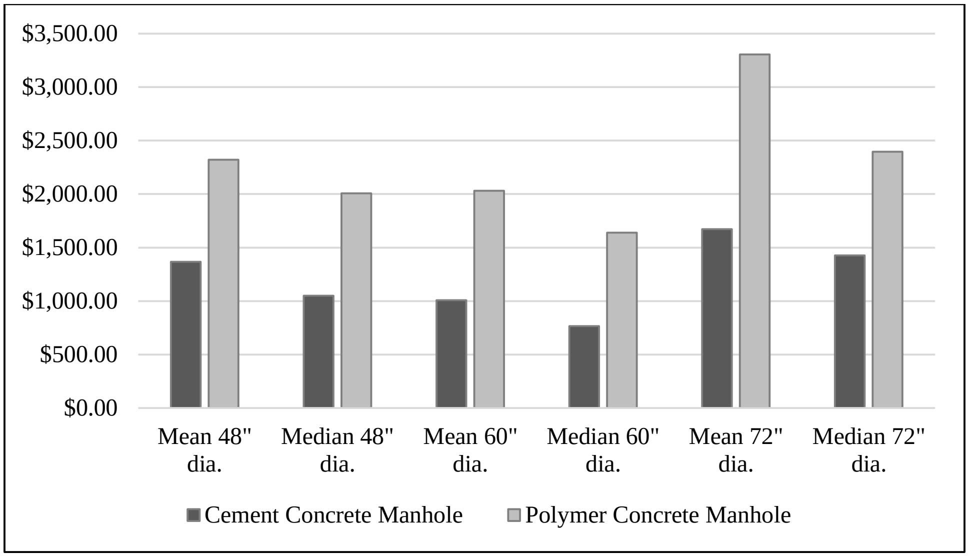

Fig. 9: Comparison of Installation Costs per feet (Mean and Median) between Cement Concrete and Polymer Concrete Manholes (1977-2017)

4.2.2.2 From 2015 to 2017

For the comparison of installation costs per feet from 2015 to 2017, the sample size of cement concrete and polymer concrete manholes were 363 and 127 respectively. The distribution of the number of different diameters of manholes are represented in the following figure:

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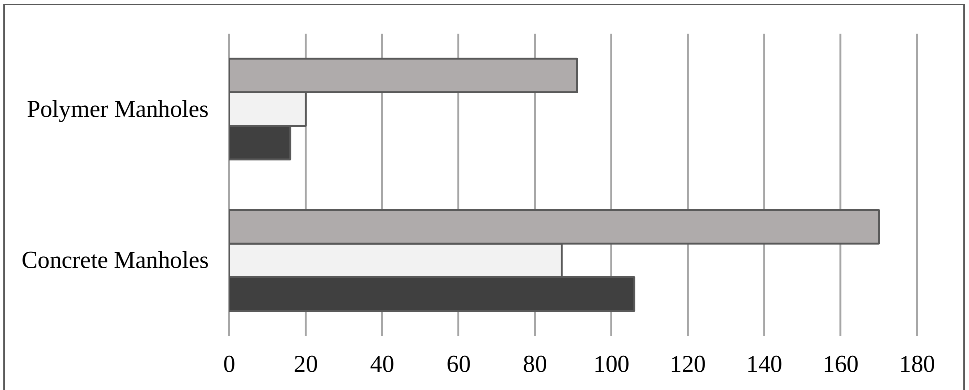

	Concrete Manholes	Polymer Manholes
72" Diameter	170	91
60" Diameter	87	20
48" Diameter	106	16

Fig. 10: Number of Cement Concrete and Polymer Concrete Manholes of different diameters for Comparison of Installation Cost per feet (2015-2017)

Further, the following charts show the descriptive statistics of both cement concrete and polymer concrete manholes:

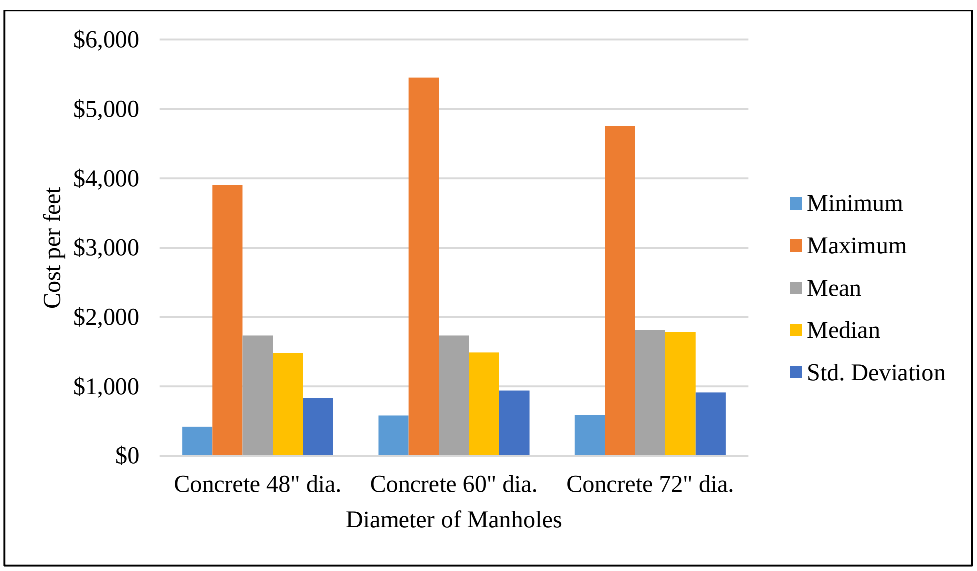

Fig. 11: Descriptive Statistics of Installation Cost per feet of Concrete Manholes (2015-2017)

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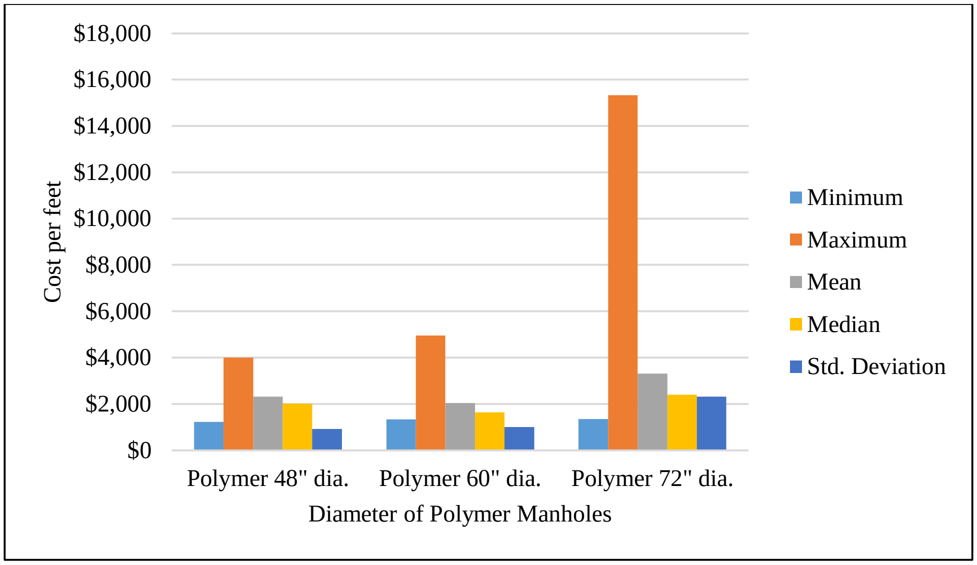

Fig. 12: Descriptive Statistics of Installation Cost per feet of Polymer Concrete Manholes (2015-2017)

The comparison of mean and median values of the installation costs per feet between the cement concrete and polymer concrete manholes of different diameters, for the duration 2015-2017, shows the higher cost of polymer concrete manholes. The comparison is shown in the figure below:

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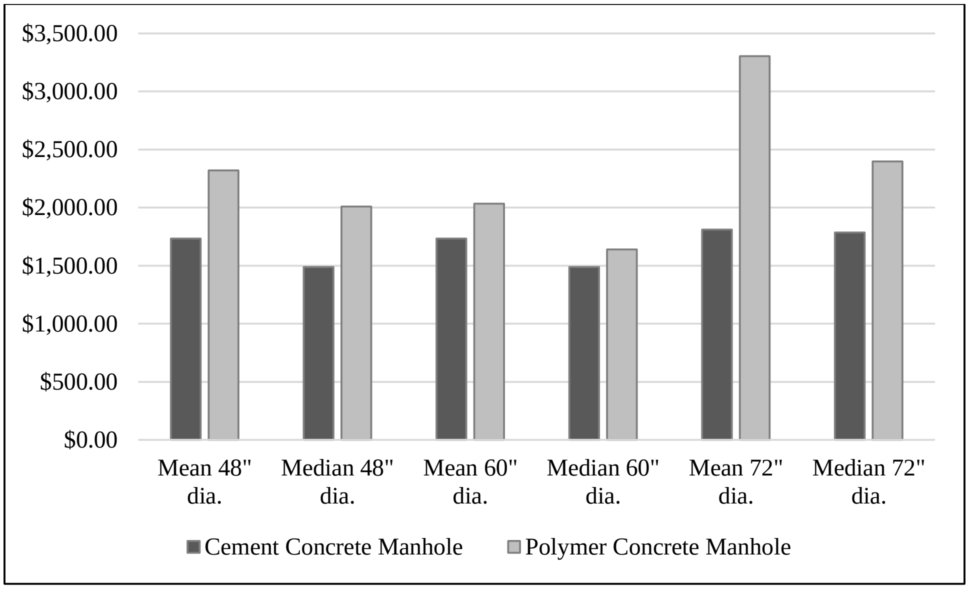

Fig. 13: Comparison of Installation Costs per feet (Mean and Median) between Cement Concrete and Polymer Concrete Manholes (2015-2017)

4.2.3 Comparison of Installation and Rehabilitation Costs between Cement Concrete and Polymer Concrete Manholes

This section includes descriptive statistics of installation and rehabilitation costs of cement concrete manholes and polymer concrete manholes.

4.2.3.1 From 1977 to 2017

a. Service life of Polymer Concrete Manholes as 50 years

For the comparison of installation and rehabilitation costs per feet per year from 1977 to 2017 with the service life of cement concrete manholes as 23 years and polymer concrete manholes as 50 years, the sample size of cement concrete and polymer concrete manholes were 1148 and 127 respectively. The distribution of the number of different diameter of manholes are represented in the following figure:

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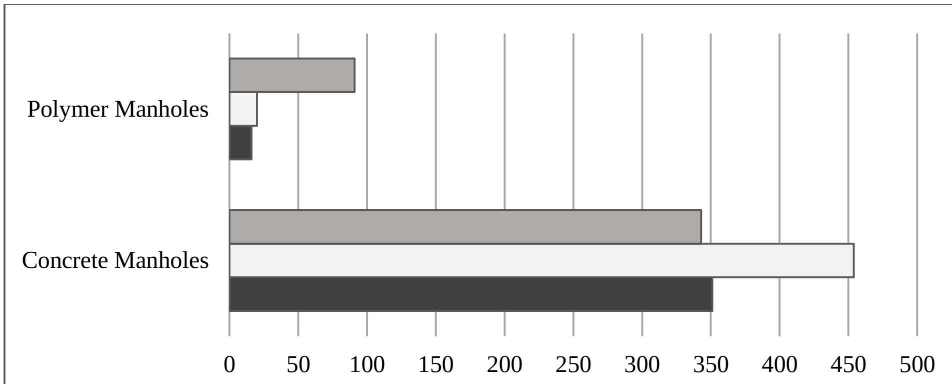

	Concrete Manholes	Polymer Manholes
72" Diameter	343	91
60" Diameter	454	20
48" Diameter	351	16

Fig. 14: Number of Cement Concrete and Polymer Concrete Manholes of different diameters for Comparison of Installation and Rehabilitation Costs per feet per year with a service life of polymer manholes as 50 years (1977-2017)

Further, the following charts show the descriptive statistics of both cement concrete and polymer concrete manholes:

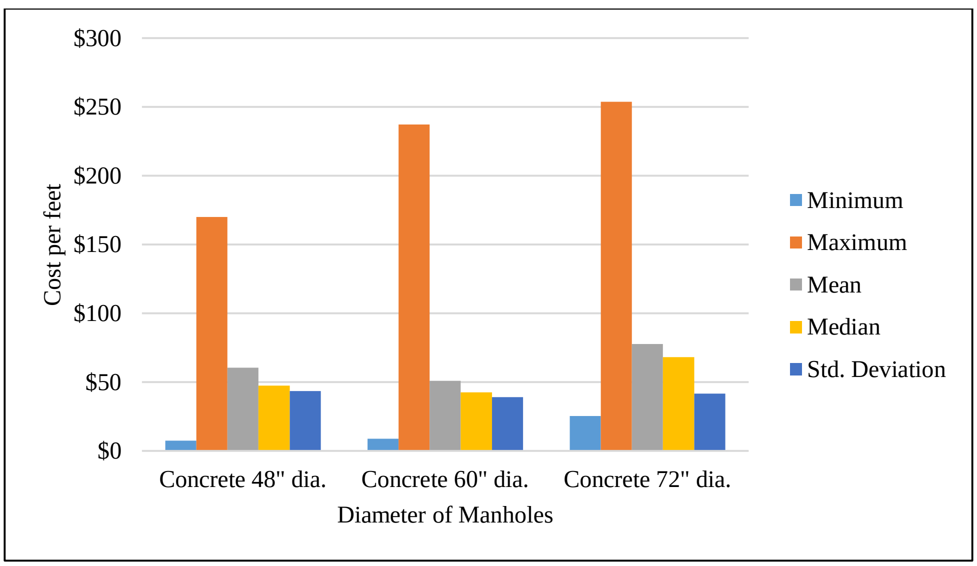

Fig. 15: Descriptive Statistics of Installation and Rehabilitation Costs per feet per year of Cement Concrete Manholes (1977-2017)

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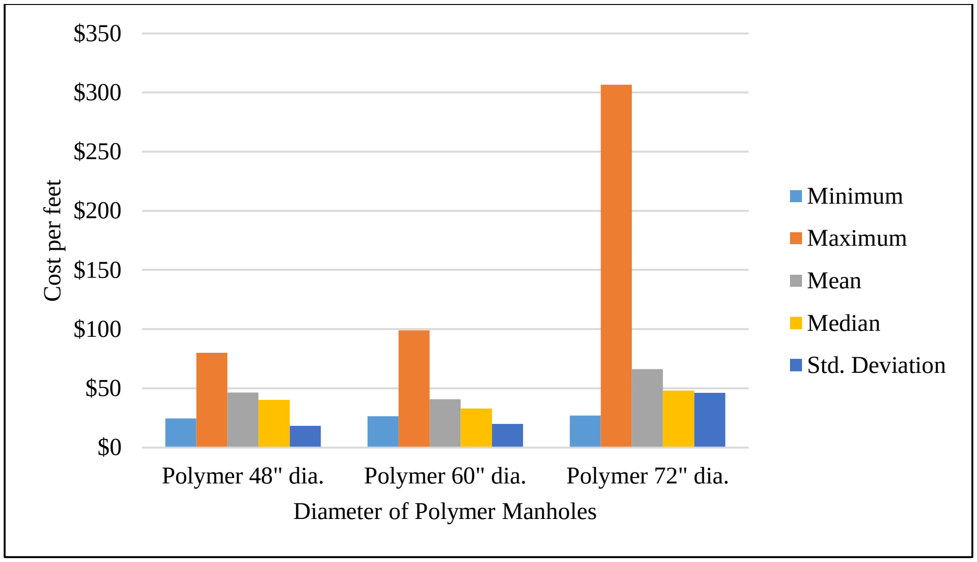

Fig. 16: Descriptive Statistics of Installation and Rehabilitation Costs per feet per year of Polymer Concrete Manholes (1977-2017)

The comparison of mean and median values of installation and rehabilitation costs of the cement concrete and polymer concrete manholes of different diameters, for the duration 1977-2017, with a service life of polymer concrete manhole as 50 years, show the comparatively lower cost of polymer concrete manholes. The comparison is shown in the figure below:

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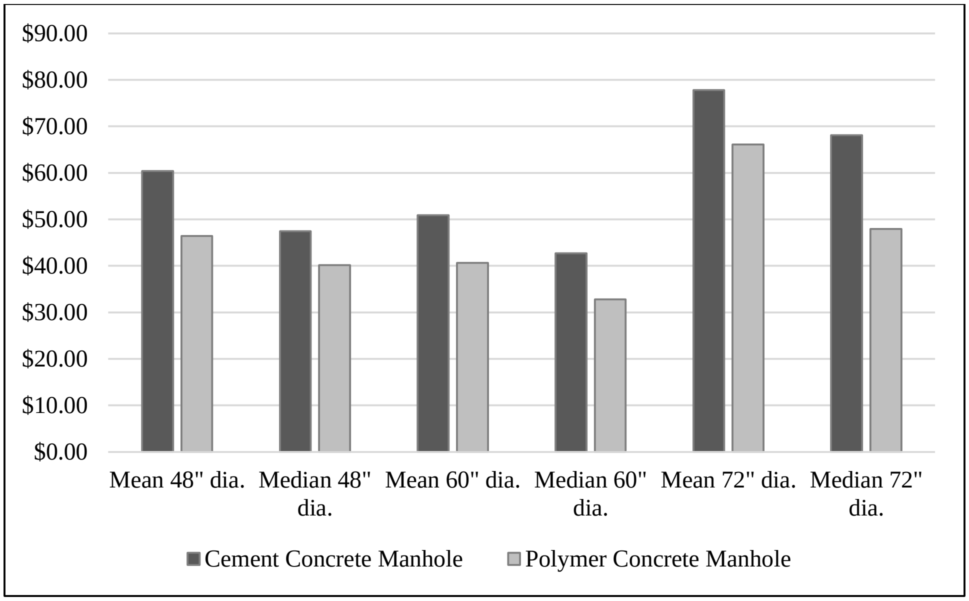

Fig. 17: Comparison of Installation and Rehabilitation Costs (Mean and Median) between Cement Concrete and Polymer Concrete Manholes (1977-2017), the service life of polymer concrete manhole as 50 years

b. Service life of Polymer Concrete Manholes as 25 years

For the comparison of installation and rehabilitation costs per feet per year from 1977 to 2017 with the service life of cement concrete manholes as 23 years and polymer concrete manholes as 25 years, the sample size of cement concrete and polymer concrete manholes were 1148 and 127 respectively. The distribution of the number of different diameter of manholes are represented in the following figure:

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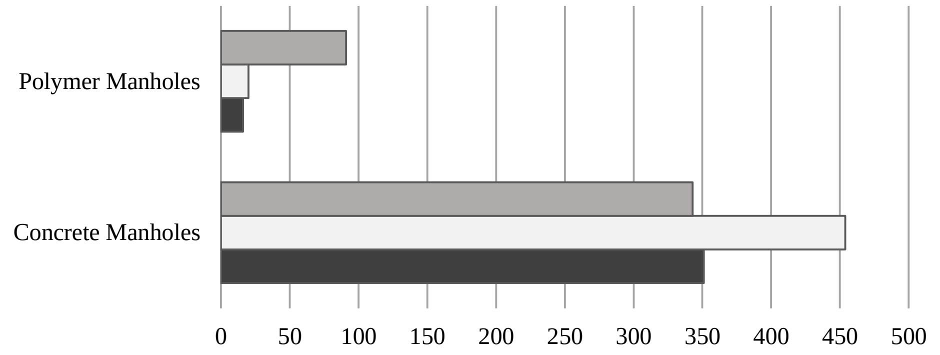

	Concrete Manholes	Polymer Manholes
72" Diameter	343	91
60" Diameter	454	20
48" Diameter	351	16

Fig. 18: Number of Cement Concrete and Polymer Concrete Manholes of different diameters for Comparison of Installation and Rehabilitation Costs per feet per year with a service life of polymer manholes as 25 years (1977-2017)

Further, the following charts show the descriptive statistics of both cement concrete and polymer concrete manholes:

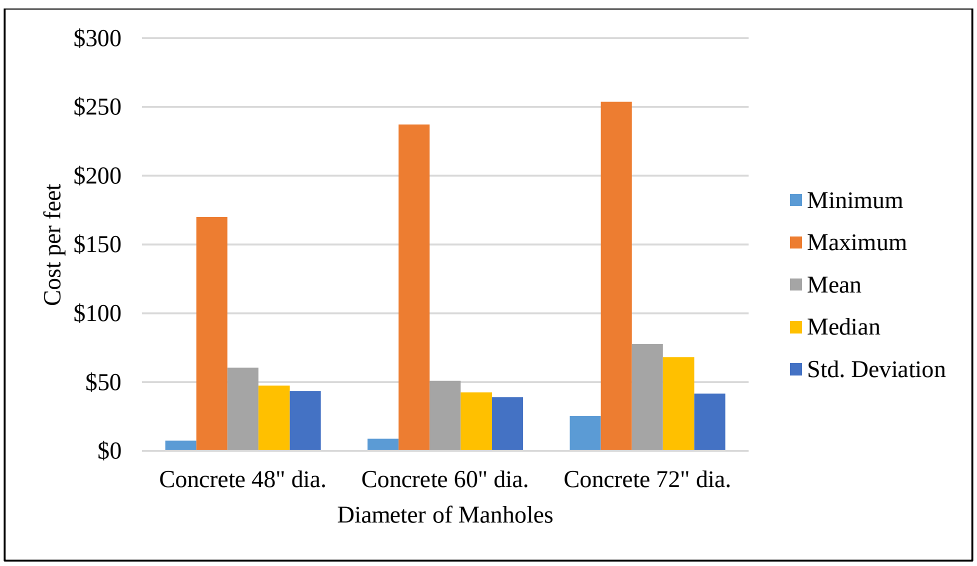

Fig. 19: Descriptive Statistics of Installation and Rehabilitation Costs per feet per year of Cement Concrete Manholes (1977-2017)

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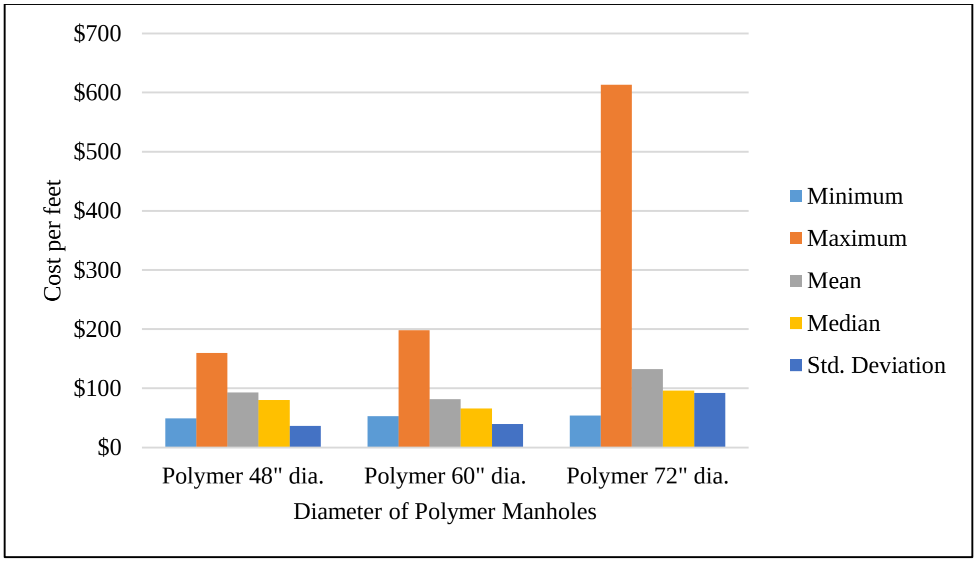

Fig. 20: Descriptive Statistics of Installation and Rehabilitation Costs per feet per year of Polymer Concrete Manholes (1977-2017)

The comparison of mean and median values of installation and rehabilitation costs between the cement concrete and polymer concrete manholes of different diameters, for the duration 1977-2017, with a service life of polymer concrete manhole as 25 years, show the comparatively higher cost of polymer concrete manholes. The comparison is shown in the figure below:

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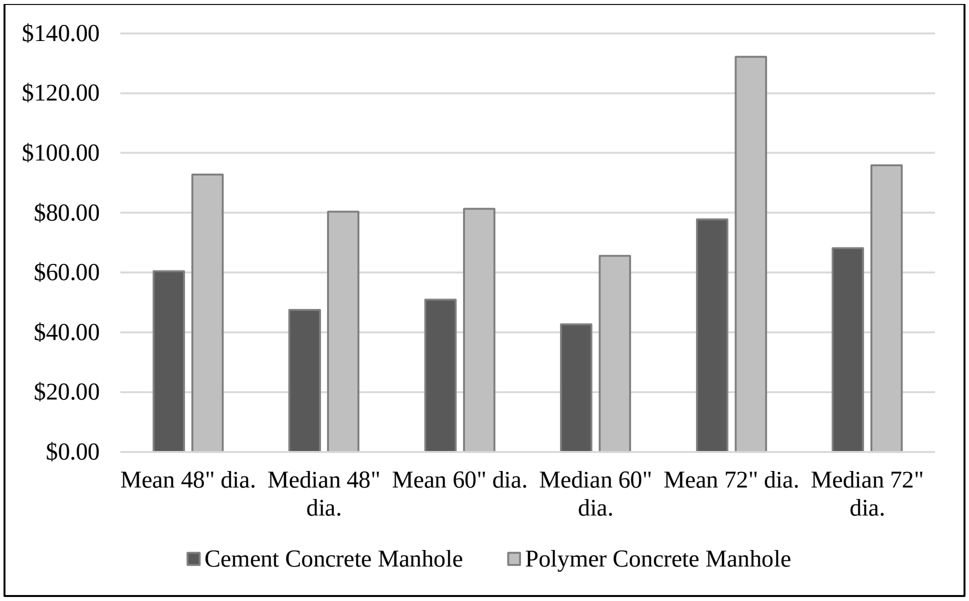

Fig. 21: Comparison of Installation and Rehabilitation Costs (Mean and Median) between Cement Concrete and Polymer Concrete Manholes (1977-2017), the service life of polymer concrete manhole as 25 years

4.2.3.2 From 2015 to 2017

a. Service life of Polymer Concrete Manholes as 50 years

For the comparison of installation and rehabilitation costs per feet per year from 2015 to 2017 with the service life of cement concrete manholes as 23 years and polymer concrete manholes as 50 years, the sample size of cement concrete and polymer concrete manholes were 349 and 127 respectively. The distribution of the number of different diameter of manholes are represented in the following figure:

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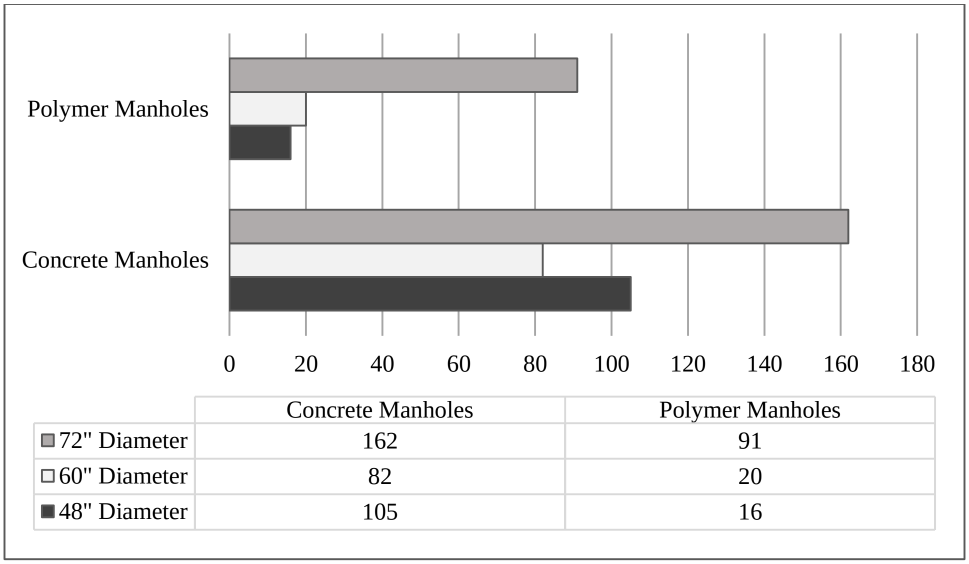

Fig. 22: Number of Cement Concrete and Polymer Concrete Manholes of different diameters for Comparison of Installation and Rehabilitation Costs per feet per year with a service life of polymer concrete manholes as 50 years (2015-2017)

Further, the following charts show the descriptive statistics of both cement concrete and polymer concrete manholes. The descriptive statistics show a uniform increment of different statistics values for both types of manholes.

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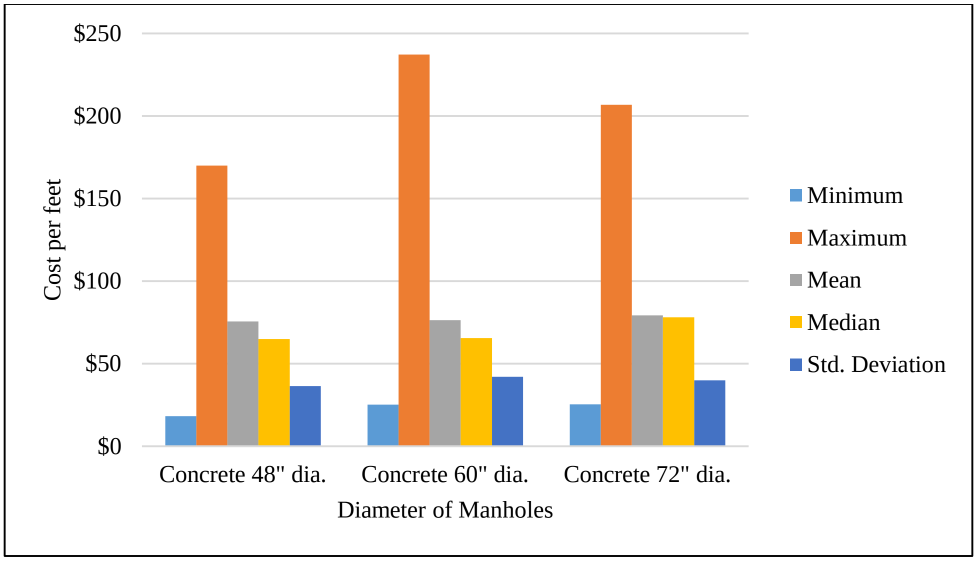

Fig. 23: Descriptive Statistics of Installation and Rehabilitation Costs per feet per year of Cement Concrete Manholes (2015-2017)

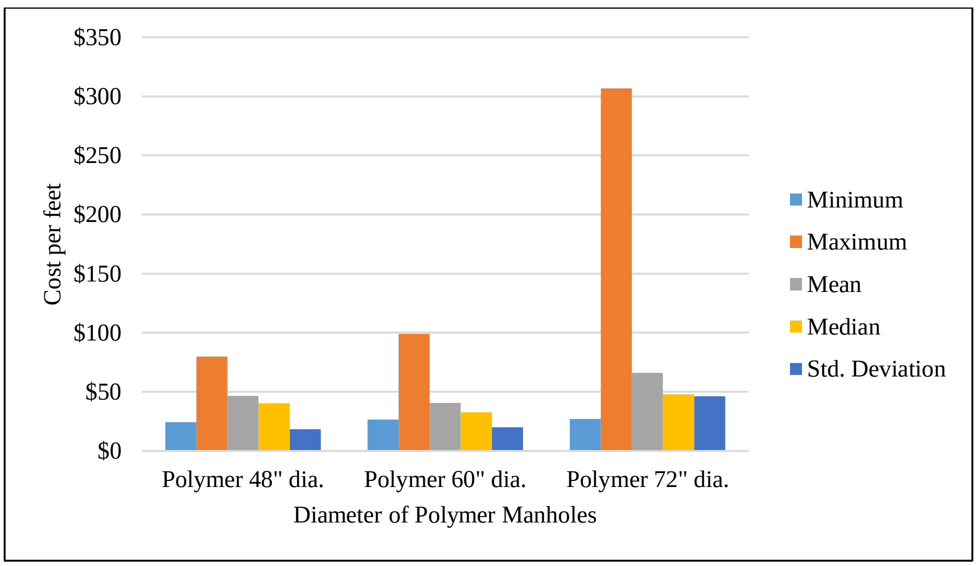

Fig. 24: Descriptive Statistics of Installation and Rehabilitation Costs per feet per year of Polymer Concrete Manholes (2015-2017)

The comparison of mean and median values of installation and rehabilitation costs between the cement concrete and polymer concrete manholes of different diameters, for the duration 2015-2017 with a service life of polymer concrete manhole as 50 years, show the

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comparatively lower cost of polymer concrete manholes. The comparison is shown in the figure below:

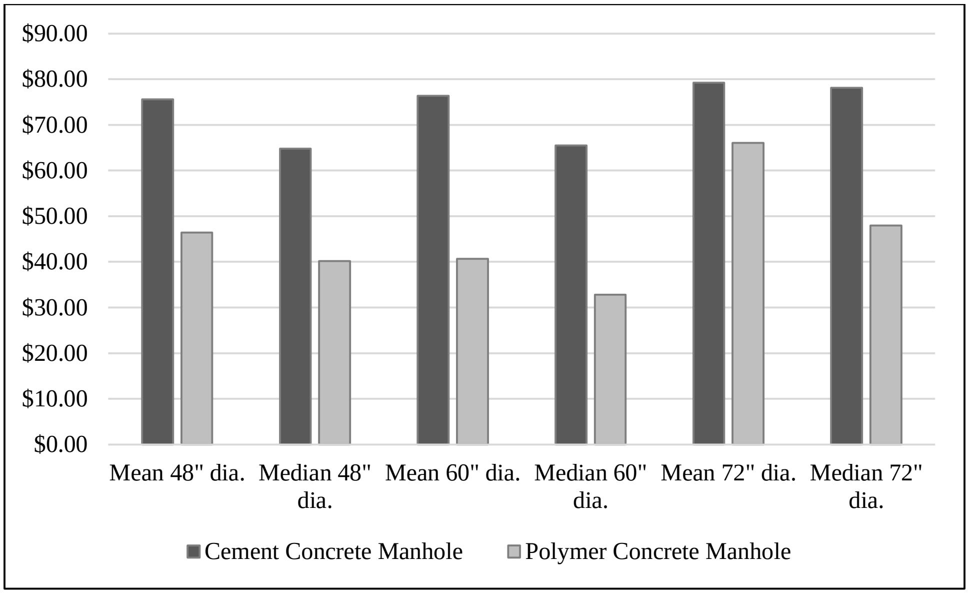

Fig. 25: Comparison of Installation and Rehabilitation Costs (Mean and Median) between Cement Concrete and Polymer Concrete Manholes (2015-2017), the service life of polymer concrete manhole as 50 years

b. Service life of Polymer Concrete Manholes as 25 years

For the comparison of installation and rehabilitation costs per feet per year from 2015 to 2017 with the service life of cement concrete manholes as 23 years and polymer concrete manholes as 25 years, the sample size of cement concrete and polymer concrete manholes were 349 and 127 respectively. The distribution of the number of different diameter of manholes are represented in the following figure:

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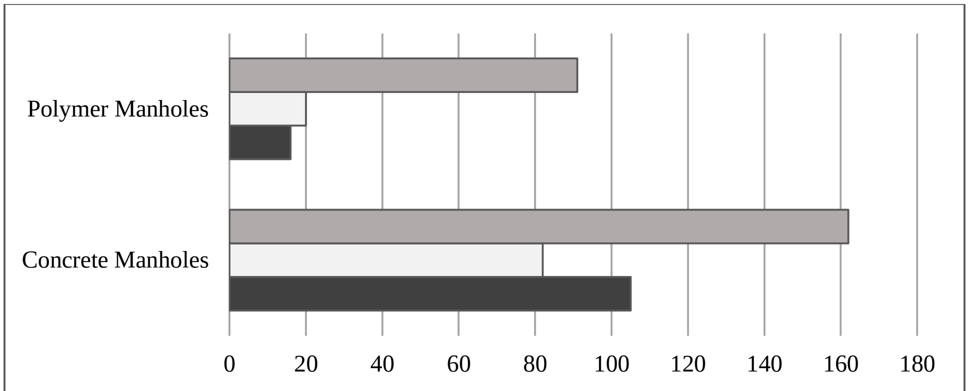

	Concrete Manholes	Polymer Manholes
72" Diameter	162	91
60" Diameter	82	20
48" Diameter	105	16

Fig. 26: Number of Cement Concrete and Polymer Concrete Manholes of different diameters for Comparison of Installation and Rehabilitation Costs per feet per year with a service life of polymer concrete manholes as 25 years (2015-2017)

Further, the following charts show the descriptive statistics of both cement concrete and polymer concrete manholes:

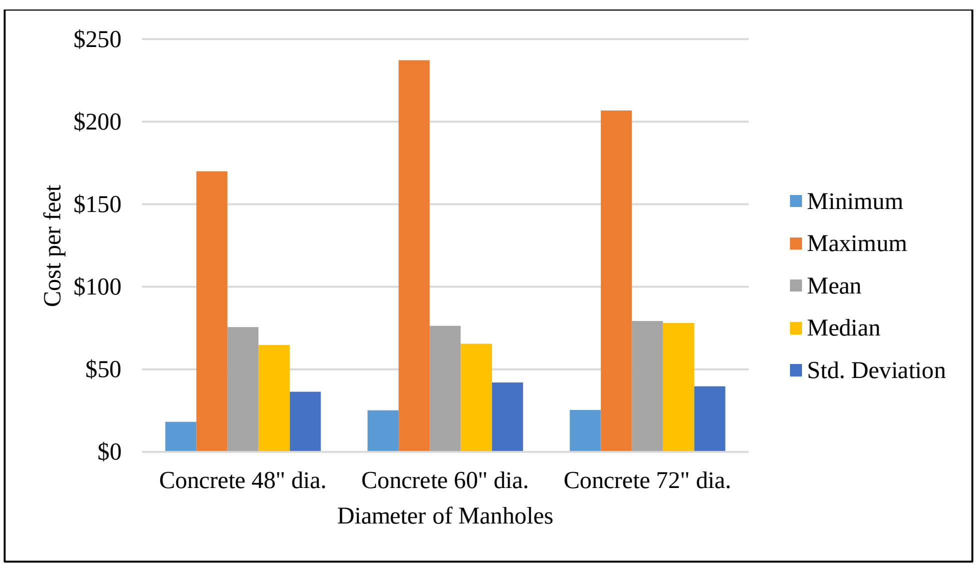

Fig. 27: Descriptive Statistics of Installation and Rehabilitation Costs per feet per year of Cement Concrete Manholes (2015-2017)

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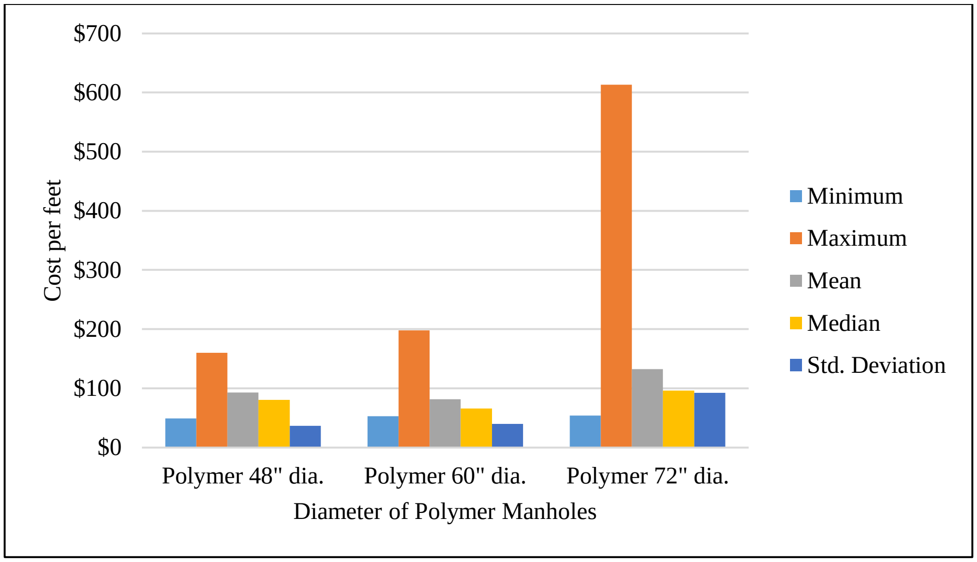

Fig. 28: Descriptive Statistics of Installation and Rehabilitation Costs per feet per year of Polymer Concrete Manholes (2015-2017)

The comparison of mean and median values of installation and rehabilitation costs of the cement concrete and polymer concrete manholes of different diameters, for the duration 2015-2017 with a service life of polymer concrete manhole as 25 years, show the comparatively higher cost of polymer concrete manholes except for the manhole of diameter 60-inch. In case of the 60-inch manholes, the costs are almost equal. The comparison is shown in the figure below:

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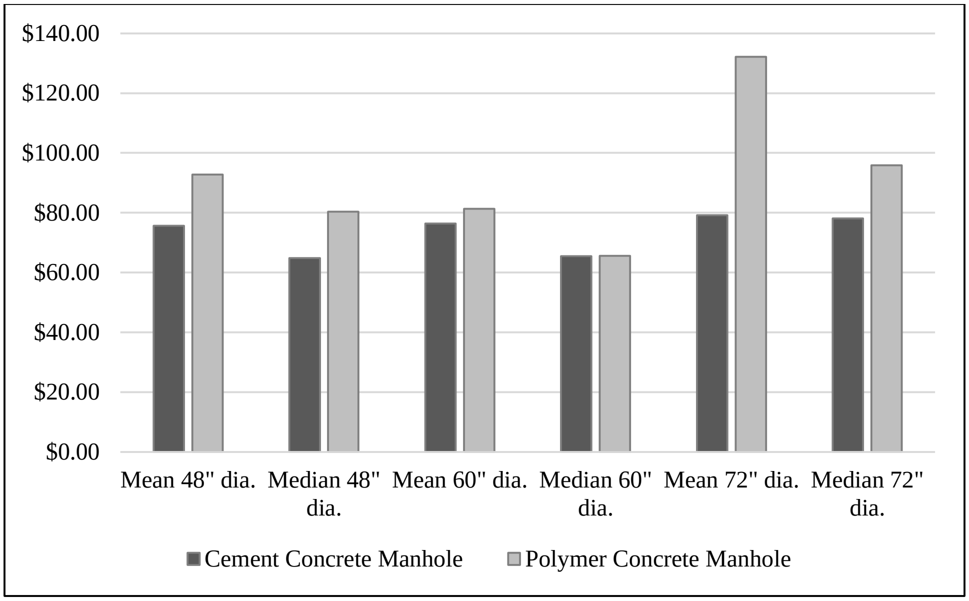

Fig. 29: Comparison of Installation and Rehabilitation Costs (Mean and Median) between Cement Concrete and Polymer Concrete Manholes (2015-2017), the service life of polymer concrete manhole as 25 years

4.3 Inferential Statistics

This section includes the inferential statistical analysis of the cost comparisons between cement concrete and polymer concrete manholes. For each condition described in this section, tests were conducted separately for three groups of different diameters: 48-inch, 60-inch, and 72-inch. It was decided to conduct t-Test for two independent samples with unequal variances for all three groups to determine whether the costs of cement concrete and polymer concrete manholes are significantly different from one another. However, due to a smaller sample size of polymer concrete manholes of 48-inch and 60-inch diameters, it was decided to conduct the non-parametric test called Mann-Whitney U test for the first two groups of manholes of diameter 48-inch and 60-inch. Both the tests were conducted taking significance value of 0.05. However, the significance (alpha) value needs a correction as the tests were conducted for three separate group analysis in each case of comparison. Bonferroni correction was applied to the significance value

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by dividing the significance value with the number of the test group, i.e., the corrected alpha value for determining significance is 0.05/3 = 0.0167. Thus, if the p-value obtained from the test are found to be less than 0.0167, then it fails to reject the null hypothesis.

4.3.1 Comparison between Installation Cost and Rehabilitation Cost of Cement Concrete Manholes

The t-Test for two samples assuming unequal variances was conducted to determine whether the installation cost per feet and rehabilitation cost per feet of cement concrete manholes of different diameter are significantly different from each other for the duration from 2006 to 2017. The null hypothesis for this test was that the mean installation cost per feet and mean rehabilitation cost per feet of cement concrete manholes are equal. The following table enlists details of the test results.

Table 4: t-Test for two samples with unequal variance for comparison between Installation Cost per feet and Rehabilitation Cost per feet of Cement Concrete Manholes (2006-2017)

Cost Metric (Cost per feet)	Diameter of Manhole	Manhole Material	Sample Size	Mean	Median	P-value (two-tail)
Installation	48-inch	Concrete	215	$1,928.26	$1,735.62	0.000*
Rehabilitation			376	$1,395.36	$1,316.07	
Installation	60-inch	Concrete	193	$1,613.62	$1,418.55	0.018
Rehabilitation			496	$1,457.69	$1,389.09	
Installation	72-inch	Concrete	317	$1,717.89	$1,478.86	0.172
Rehabilitation			173	$1,600.46	$1,347.47	

* significant at alpha level 0.0167

From the summary of test results, it can be seen that the p-value for 48-inch diameter manholes is less than 0.0167, i.e., it rejects the null hypothesis. It shows that, for the 48-inch

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diameter cement concrete manholes, the mean installation cost per feet is significantly different from the mean rehabilitation cost per feet. However, in case of 60-inch and 72-inch cement concrete manholes, the p-value is greater than 0.0167, i.e., the null hypothesis is accepted for both. It shows that, for the 60-inch and 72-inch diameter concrete manholes, the mean installation cost per feet and rehabilitation cost per feet are not significantly different.

4.3.2 Comparison of Installation Costs between Cement Concrete and Polymer Manholes

4.3.2.1 From 1977 to 2017

As discussed above, Mann-Whitney U test was conducted to determine whether the installation costs of cement concrete and polymer concrete manholes of 48-inch and 60-inch diameter are significantly different for the duration from 1977 to 2017. The null hypothesis for this test was that the median values of the installation costs per feet of the two types of manholes are equal. The following table enlists details of test results:

Table 5: Mann-Whitney U Test for comparison of Installation Cost per feet between Cement Concrete and Polymer Concrete Manholes (1977-2017)

Cost Metric	Diameter of Manhole	Manhole Material	Sample Size	Mean	Median	P-value (two-tail)
Installation Cost per feet	48-inch	Concrete	353	$1,366.57	$1,051.05	0.000*
		Polymer	16	$2,320.46	$2,008.13	
Installation Cost per feet	60-inch	Concrete	460	$1,008.52	$766.90	0.000*
		Polymer	20	$2,032.37	$1,639.53	

* significant at alpha level 0.0167

From the summary of test results, it can be seen that the p-values for both 48-inch and 60-inch diameter of manholes are less than 0.0167, i.e., it rejects the null hypotheses. It shows that the median installation costs per feet of both types of manholes are significantly different. Hence,

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we can conclude that the installation cost per feet of polymer concrete manholes is significantly higher than that of cement concrete manholes.

Similarly, t-Test for two samples assuming unequal variances was conducted to determine whether the installation costs of cement concrete and polymer concrete manholes of 72-inch diameter are significantly different for the duration from 1977 to 2017. The null hypothesis for this test was that the mean installation costs per feet of the two types of manholes are equal. The following table enlists details of the test results:

Table 6: t-Test for two samples with unequal variance for comparison of Installation Cost per feet between Cement Concrete and Polymer Concrete Manholes (1977-2017)

Cost Metric	Diameter of Manhole	Manhole Material	Sample Size	Mean	Median	P-value (two-tail)
Installation Cost per feet	72-inch	Concrete	353	$1,673.38	$1,426.16	0.000*
		Polymer	91	$3,304.27	$2,396.31	

* significant at alpha level 0.0167

From the summary of test results, it can be seen that the p-value for 72-inch diameter manholes is less than 0.0167, i.e., it rejects the null hypothesis. It shows that the mean installation costs per feet of the two types of manholes are significantly different. Hence, we can conclude that the installation cost per feet of polymer concrete manholes is significantly higher than that of cement concrete manholes.

4.3.2.2 From 2015 to 2017

The Mann-Whitney U tests were repeated to determine whether the installation costs of cement concrete and polymer concrete manholes of 48-inch and 60-inch diameter are significantly different for the duration from 2015 to 2017. The null hypothesis for this test was

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that the median values of the installation costs per feet of the two types of manholes are equal. The following table enlists details of test results:

Table 7: Mann-Whitney U Test for comparison of Installation Cost per feet between Cement Concrete and Polymer Concrete Manholes (2015-2017)

Cost Metric	Diameter of Manhole	Manhole Material	Sample Size	Mean	Median	P-value (two-tail)
Installation Cost per feet	48-inch	Concrete	106	$1,732.99	$1,486.94	0.010*
		Polymer	16	$2,320.46	$2,008.13	
Installation Cost per feet	60-inch	Concrete	87	$1,733.79	$1,488.92	0.063
		Polymer	20	$2,032.37	$1,639.53	

* significant at alpha level 0.0167

From the summary of test results, it can be seen that the p-value for 48-inch diameter manhole is less than 0.0167, i.e., it rejects the null hypothesis. Hence, we can conclude that the installation cost per feet of polymer concrete manholes is significantly higher than that of cement concrete manholes for 48-inch diameter. However, the p-value for 60-inch diameter manhole is greater than 0.0167, i.e., it accepts the null hypothesis. Therefore, the installation costs per feet are not significantly different in case of 60-inch diameter manholes.

Similarly, t-Test for two samples assuming unequal variances was conducted to determine whether the installation costs of cement concrete and polymer concrete manholes of 72-inch diameter are significantly different for the duration from 2015 to 2017. The null hypothesis for this test was that the mean installation costs per feet of the two types of manholes are equal. The following table enlists details of the test results:

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Table 8: t-Test for two samples with unequal variance for comparison of Installation Cost per feet between Cement Concrete and Polymer Concrete Manholes (2015-2017)

Cost Metric	Diameter of Manhole	Manhole Material	Sample Size	Mean	Median	P-value (two-tail)
Installation Cost per feet	72-inch	Concrete	170	$1,810.10	$1,785.28	0.000*
		Polymer	91	$3,304.27	$2,396.31	

* significant at alpha level 0.0167

From the summary of test results, it can be seen that the p-value for 72-inch diameter manholes is less than 0.0167, i.e., it rejects the null hypothesis. It shows that the mean installation costs per feet of the two types of manholes are significantly different. Hence, we can conclude that the installation cost per feet of polymer concrete manholes is significantly higher than that of cement concrete manholes for the manholes installed from 2015 to 2017.

4.3.3 Comparison of Installation and Rehabilitation Costs between Cement Concrete and Polymer Concrete Manholes

4.3.3.1 From 1977 to 2017

a. Service life of Polymer Concrete Manholes as 50 years

The Mann-Whitney U tests were repeated to determine whether the installation and rehabilitation costs per feet per year of cement concrete and polymer concrete manholes of 48-inch and 60-inch diameter are significantly different. The comparison includes installation and rehabilitation costs for cement concrete manholes installed from 1977 to 2017 with a service life of 23 years and the polymer concrete manholes installed from 2015 to 2017 with a service life of 50 years. The null hypothesis for the test was that the median value of installation and rehabilitation costs per feet per year of the two types of manholes are equal. The following table enlists details of the test results:

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Table 9: Mann-Whitney U Test for comparison of Installation and Rehabilitation Cost per feet per year between Cement Concrete and Polymer Concrete Manholes (1977-2017) – 50 years of service life of Polymer Concrete Manholes

Cost Metric	Diameter of Manhole	Manhole Material	Sample Size	Mean	Median	P-value (two-tail)
Installation and Rehabilitation Costs per feet per year	48-inch	Concrete	351	$60.42	$47.48	0.727
		Polymer	16	$46.41	$40.17	
	60-inch	Concrete	454	$50.91	$42.69	0.683
		Polymer	20	$40.65	$32.79	

From the summary of test results, it can be seen that the p-values for both 48-inch and 60-inch diameter manholes are greater than 0.0167, i.e., it accepts the null hypotheses. It shows that the median value of installation and rehabilitation costs per feet per year of both types of manholes are not significantly different. Hence, we can conclude the installation and rehabilitation costs per feet per year of polymer concrete manholes with 50 years of service life are not significantly different from that of cement concrete manholes with 23 years of service life in case of both 48-inch and 60-inch diameter.

Similarly, t-Test for two samples assuming unequal variances was conducted in case of the 72-inch cement concrete manholes installed from 1977 to 2017 with a service life of 23 years and the 72-inch polymer concrete manholes installed from 2015 to 2017 with a service life of 50 years. The null hypothesis for this test was that the mean value of installation and rehabilitation costs per feet per year of the two types of manholes of 72-inch diameter are equal. The following table enlists details of the test results:

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Table 10: t-Test for two samples with unequal variance for comparison of Installation and Rehabilitation Costs per feet per year between Cement Concrete and Polymer Concrete Manholes (1977-2017) – 50 years of service life of Polymer Concrete Manholes

Cost Metric	Diameter of Manhole	Manhole Material	Sample Size	Mean	Median	P-value (two-tail)
Installation and Rehabilitation Costs per feet per year	72-inch	Concrete	343	$77.83	$68.11	0.029
		Polymer	91	$66.09	$47.93	

From the summary of test results, it can be seen that the p-value for 72-inch diameter manholes is also greater than 0.0167, i.e., it accepts the null hypothesis. It shows that the mean value of the installation and rehabilitation costs per feet per year of the two types of manholes are not significantly different. Hence, we can conclude that the installation and rehabilitation costs per feet per year of polymer concrete manholes with 50 years of service life are not significantly different from that of cement concrete manholes with 23 years of service life in case of 72-inch diameter as well.

b. Service life of Polymer Concrete Manholes as 25 years

Mann-Whitney U tests were repeated to determine whether the installation and rehabilitation costs per feet per year of cement concrete manholes with a service life of 23 years and polymer concrete manholes with a service life of 25 years are significantly different in the case of 48-inch and 60-inch diameter manholes. The comparison includes installation and rehabilitation costs for cement concrete manholes installed from 1977 to 2017 and the polymer concrete manholes installed from 2015 to 2017. The null hypothesis for the test was that the

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median value of the installation and rehabilitation costs per feet per year of the two types of manholes are equal. The following table enlists details of the test results:

Table 11: Mann-Whitney U Test for comparison of Installation and Rehabilitation Costs per feet per year between Cement Concrete and Polymer Concrete Manholes (1977-2017) – 25 years of service life of Polymer Concrete Manholes

Cost Metric	Diameter of Manhole	Manhole Material	Sample Size	Mean	Median	P-value (two-tail)
Installation and Rehabilitation Costs per feet per year	48-inch	Concrete	351	$60.42	$47.48	0.001*
		Polymer	16	$92.82	$80.33	
	60-inch	Concrete	454	$50.91	$42.69	0.000*
		Polymer	20	$81.30	$65.59	

* significant at alpha level 0.0167

From the summary of test results, it can be seen that the p-values for both 48-inch and 60-inch diameter manholes are less than 0.0167, i.e., it rejects the null hypotheses. It shows that the median value of the installation and rehabilitation costs per feet per year of both types of manholes are significantly different. Hence, we can conclude the installation and rehabilitation costs per feet per year of polymer concrete manholes with 25 years of service life are significantly higher than that of cement concrete manholes with 23 years of service life in case of both 48-inch and 60-inch diameter.

Similarly, t-Test for two samples assuming unequal variances was conducted in case of the 72-inch cement concrete manholes installed from 1977 to 2017 with a service life of 23 years and the 72-inch polymer concrete manholes installed from 2015 to 2017 with service life to 25 years. The null hypothesis for this test was that the mean value of the installation and rehabilitation costs per feet per year of the two types of manholes of 72-inch diameter are equal. The following table enlists details of the test results:

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Table 12: t-Test for two samples with unequal variance for comparison of Installation and Rehabilitation Costs per feet per year between Cement Concrete and Polymer Concrete Manholes (1977-2017) – 25 years of service life of Polymer Concrete Manholes

Cost Metric	Diameter of Manhole	Manhole Material	Sample Size	Mean	Median	P-value (two-tail)
Installation and Rehabilitation Costs per feet per year	72-inch	Concrete	343	$77.83	$68.11	0.000*
		Polymer	91	$132.17	$95.85	

* significant at alpha level 0.0167

From the summary of test results, it can be seen that the p-value for 72-inch diameter manholes is less than 0.0167, i.e., it rejects the null hypothesis. It shows that the mean value of the installation and rehabilitation costs per feet per year of the two types of manholes are significantly different. Hence, we can conclude the installation and rehabilitation costs per feet per year of polymer concrete manholes with 25 years of service life are significantly higher than that of cement concrete manholes with 23 years of service life in case of 72-inch diameter as well.

4.3.3.2 From 2015 to 2017

a. Service life of Polymer Concrete Manholes as 50 years

For the duration from 2015 to 2017, the Mann-Whitney U tests were repeated to determine whether the installation and rehabilitation costs per feet per year of cement concrete manholes with a service life of 23 years and polymer concrete manholes with 50 years of service life are significantly different in case of 48-inch and 60-inch diameter. The null hypothesis for the test was that the median value of installation and rehabilitation costs per feet per year of the two types of manholes are equal. The following table enlists details of the test results:

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Table 13: Mann-Whitney U Test for comparison of Installation and Rehabilitation Costs per feet per year between Cement Concrete and Polymer Concrete Manholes (2015-2017) – 50 years of service life of Polymer Concrete Manholes

Cost Metric	Diameter of Manhole	Manhole Material	Sample Size	Mean	Median	P-value (two-tail)
Installation and Rehabilitation Costs per feet per year	48-inch	Concrete	105	$75.62	$64.82	0.001*
		Polymer	16	$46.41	$40.17	
	60-inch	Concrete	82	$76.35	$65.49	0.000*
		Polymer	20	$40.65	$32.79	

* significant at alpha level 0.0167

From the summary of test results, it can be seen that the p-values for both 48-inch and 60-inch diameter of manholes are less than 0.0167, i.e., it rejects the null hypotheses. It shows that the median value of the installation and rehabilitation costs per feet per year of both types of manholes are significantly different. Hence, we can conclude that the installation and rehabilitation costs per feet per year of polymer concrete manholes with 50 years of service life are significantly higher than that of cement concrete manholes with 23 years of service life in case of both 48-inch and 60-inch diameter, both installed from 2015 to 2017.

Similarly, t-Test for two samples assuming unequal variances was conducted in case of the 72-inch cement concrete manholes with a service life of 23 years and polymer concrete manholes with a service life of 50 years; both installed from 2015 to 2017. The null hypothesis for this test was that the mean value of the installation and rehabilitation costs per feet per year of the two types of manholes of 72-inch diameter are equal. The following table enlists details of the test results:

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Table 14: t-Test for two samples with unequal variance for comparison of Installation and Rehabilitation Costs per feet per year between Cement Concrete and Polymer Concrete Manholes (2015-2017) – 50 years of service life of Polymer Concrete Manholes

Cost Metric	Diameter of Manhole	Manhole Material	Sample Size	Mean	Median	P-value (two-tail)
Installation and Rehabilitation Costs per feet per year	72-inch	Concrete	162	$79.22	$78.12	0.024
		Polymer	91	$66.09	$47.93	

From the summary of test results, it can be seen that the p-value for 72-inch diameter manholes is greater than 0.0167, i.e., it accepts the null hypothesis. Hence, we can conclude that, for the period from 2015 to 2017, the installation and rehabilitation costs per feet per year of polymer concrete manholes with 50 years of service life and cement concrete manholes with 23 years of service life in case of 72-inch diameter are not significantly different.

b. Service life of Polymer Concrete Manholes as 25 years

Again, for the duration from 2015 to 2017, the Mann-Whitney U tests were repeated to determine whether the installation and rehabilitation costs per feet per year of cement concrete manholes with a service life of 23 years and polymer concrete manholes with a service life of 25 years are significantly different for both 48-inch and 60-inch diameter. The null hypothesis for the test was that the median value of the installation and rehabilitation costs per feet per year of the two types of manholes are equal. The following table enlists details of the test results:

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Table 15: Mann-Whitney U Test for comparison of Installation and Rehabilitation Costs per feet per year between Cement Concrete and Polymer Concrete Manholes (2015-2017) – 25 years of service life of Polymer Concrete Manholes

Cost Metric	Diameter of Manhole	Manhole Material	Sample Size	Mean	Median	P-value (two-tail)
Installation and Rehabilitation Costs per feet per year	48-inch	Concrete	105	$75.62	$64.82	0.045
		Polymer	16	$92.82	$80.33	
	60-inch	Concrete	82	$76.35	$65.49	0.358
		Polymer	20	$81.30	$65.59	

From the summary of test results, it can be seen that the p-values for both 48-inch and 60-inch diameter of manholes are greater than 0.0167, i.e., it accepts the null hypotheses. It shows that the median value of the installation and rehabilitation costs per feet per year of both types of manholes are not significantly different. Hence, we can conclude that the installation and rehabilitation costs per feet per year of polymer concrete manholes with 25 years of service life are not significantly different from that of cement concrete manholes with 23 years of service life in case of both 48-inch and 60-inch diameter, both installed from 2015 to 2017.

Similarly, t-Test for two samples assuming unequal variances was conducted in case of the 72-inch cement concrete manholes with a service life of 23 years and polymer concrete manholes with a service life of 25 years; both installed from 2015 to 2017. The null hypothesis for this test was that the mean value of the installation and rehabilitation costs per feet per year of the two types of manholes of 72-inch diameter are equal. The following table enlists details of the test results:

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Table 16: t-Test for two samples with unequal variance for comparison of Installation and Rehabilitation Cost per feet per year between Cement Concrete and Polymer Concrete Manholes (2015-2017) – 25 years of service life of Polymer Concrete Manholes

Cost Metric	Diameter of Manhole	Manhole Material	Sample Size	Mean	Median	P-value (two-tail)
Installation and Rehabilitation Costs per feet per year	72-inch	Concrete	162	$79.22	$78.12	0.000*
		Polymer	91	$132.17	$95.85	

* significant at alpha level 0.0167

From the summary of test results, it can be seen that the p-value for 72-inch diameter manholes is less than 0.0167, i.e., it rejects the null hypothesis. It shows that the mean value of the installation and rehabilitation costs per feet per year of the two types of manholes are significantly different. Hence, we can conclude that, for the duration from 2015 to 2017, the installation and rehabilitation costs per feet per year of polymer concrete manholes with 25 years of service life are significantly higher than that of cement concrete manholes with 23 years of service life in case of 72-inch diameter.

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CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study on the comparison of costs associated with cement concrete and polymer concrete manholes installed in the city of Las Vegas was successfully conducted with the cost data available from Clark County Water Reclamation District (CCWRD). Out of approximately 45,000 manholes in Las Vegas, the study included a total of 1145 newly installed, 18 replaced, and 1045 rehabilitated cement concrete manholes as well as 127 polymer concrete manholes. The data was extracted from a total of 64 projects completed between 1977 to 2017 out of which only six projects had polymer concrete manholes that were installed from 2015 to 2017.

The average duration of both replacement and rehabilitation of cement concrete manholes was determined to be approximately 23 years. Hence, 23 years of service life was considered for cement concrete manholes. However, in the case of polymer concrete manholes, the service life of 50 years was considered based on the manufacturer's information.

From the comparison between installation and rehabilitation costs of the cement concrete manholes for the duration from 2006 to 2017, it was determined that the rehabilitation costs per feet are significantly different from the installation cost per feet in the case of 48-inch cement concrete manholes. However, the two costs are not significantly different in the case of 62-inch and 72-inch cement concrete manholes.

The cement concrete and polymer concrete manholes were compared based on their installation costs per feet and the combined installation and rehabilitation costs per feet per year. The comparison of installation costs of the two types of manholes of 48-inch, 60-inch, and 72-inch separately showed that the installation costs per feet of the polymer concrete manholes installed from 2015 to 2017 are significantly greater than that of cement concrete manholes

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installed from 1977 to 2017. Similarly, comparison of installation costs of 48-inch and 72-inch diameter manholes of both types installed from 2015 to 2017 showed significantly higher installation cost of polymer concrete manholes. However, the installation cost per feet of 60-inch manholes is not significantly different.

The combined installation and rehabilitation costs based on 23 years and 50 years of service life of cement concrete and polymer concrete manholes respectively were compared. The comparison of installation and rehabilitation costs of cement concrete manholes installed from 1977 to 2017 with polymer concrete manholes installed from 2015 to 2017 showed that the installation and rehabilitation costs per feet per year for both types of manholes are not significantly different from each other. However, the costs were found to be significantly different while considering the service life of polymer concrete manholes to be 25 years only. If the polymer concrete manholes would only serve for a period of 25 years, then the installation and rehabilitation costs of polymer concrete manholes are significantly higher than that of cement concrete manholes.

For more reliability of the study, installation and rehabilitation costs of both types of manholes installed from 2015 to 2017 were also compared with both 50 years and 25 years as the service life of polymer concrete manholes. The results showed that the installation and rehabilitation costs per feet per year of the polymer concrete manholes are significantly lower than that of cement concrete manholes in the case of 48-inch and 60-inch diameters manholes, with 50 years of service life of polymer concrete manholes. The costs were not significantly different for 72-inch diameter manholes. However, the installation and rehabilitation cost of 72-inch polymer concrete manholes with 25 years of service life is determined to be significantly higher compared to cement concrete manholes while the installation and rehabilitation cost of

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48-inch and 60-inch polymer concrete and cement concrete manholes are not significantly different.

5.2 Recommendation

The sample size of polymer concrete manholes considered in this study was too small, mainly for the 48-inch and 60-inch sizes. A larger sample size provides more reliable cost comparison result. Hence, it is recommended to collect information on more polymer concrete manholes and conduct an extensive cost comparison between the two types. The public authorities can reliably refer to these study results for decision-making on the selection of the type of manhole for the sewer projects.

Although the cost comparison between cement concrete and polymer concrete manholes in this study included the installation and rehabilitation costs only, the installation of polymer concrete manholes clearly offers many benefits. Funding agencies save on maintenance and rehabilitation costs; time is also saved by everyone involved in the installation process. Similarly, road users save significant travel time as well as the costs of fuel, as the use of polymer concrete manholes do not require detour routes for maintenance. Further, the public benefit from reduced noise and air pollution. These benefits can be quantified in terms of cost. Besides, the use of polymer concrete manholes requires higher initial investment. Hence, if the public authorities decide on using the cement concrete manholes instead of polymer concrete manholes, they would have a significant amount of savings from the difference of installation cost to invest on other public projects. Thus, the public authorities lose investment opportunity by using polymer concrete manholes. For better cost comparison, the benefits and losses should be considered as well. Therefore, it is recommended to conduct a life-cycle benefit-cost analysis of these manholes.

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The cost information of the manholes available in this study was the lump sum costs that included the costs of labor, equipment, material, and overheads as well. However, it is known that the cost of polymer concrete is higher compared to cement concrete and also, based on the case studies, it is found that the installation of polymer concrete manholes is easier and quicker compared to installation of cement concrete manholes. Hence, it is suggested to conduct a study on the comparison of time and cost of manpower and equipment required for installation of cement concrete and polymer concrete manholes.

5.3 Discussion

According to CCWRD personnel from the maintenance division, the manholes are inspected to assess their condition, and recommendations are made to either replace or rehabilitate them. However, the replacement or rehabilitation of manholes is not carried out unless there is already a project nearby or the situation is urgent. The decision to replace a manhole is only made if its structures are in the worst condition. Otherwise, deteriorated manholes are rehabilitated to extend their useful life. USEPA has mentioned the similar behavior of public agencies in deciding for renewal of manholes (Sterling, Condit, & Wang, 2010). This behavior of the public agencies has also been supported by the information collected from CCWRD for this study, which shows that the ratio of rehabilitated manholes to replaced manholes was nearly 5:1. However, the average duration of both replacement and rehabilitation of cement concrete manholes was determined to be 23 years. This implies that public agencies tend to avoid the replacement of manholes as much as possible.

The comparison of installation and rehabilitation costs of cement concrete manholes demonstrated that the rehabilitation costs are not significantly different from the installation costs, except for the 48-inch manhole. It implies that the rehabilitation of cement concrete

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manhole is expensive. The rehabilitation work requires prior preparation work, such as cleaning of manhole surface, removal of dirt and debris, and management of existing sewage (NASSCO, 2013). Various tests are also required for quality assurance based on the system of rehabilitation applied. Further, additional safety measures are required for the safety of workers. Thus, these might be the reason behind higher cost of rehabilitating cement concrete manholes.

The cost comparison results between the manholes of different diameters showed variation. This might be due to the comparison of a smaller sample size of polymer concrete manholes with the larger samples size of cement concrete manholes in this study. A larger sample size of polymer concrete manholes might give consistent results.

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