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Analyzing the Life-Cycle Cost of Manholes: Cement Concrete Versus Polymer Concrete

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Abstract In the United States sewer networks, cement concrete (CC) manholes are widely utilized. However, due to their great susceptibility to chemical corrosion, these manholes have shorter lifespan. In comparison to CC manholes, polymer concrete (PC) manholes in sewer networks are shown to have greater resistance to chemical corrosion and longer lifespans. Despite this advantage, use of PC manholes in public works has been limited by their higher initial installation cost. There are very limited studies conducted in this subject; therefore, the key objective of this study is to compare CC and PC manholes and identify the most cost-effective option based on life-cycle costs (LCC). This study collected 60-inch and 48-inch diameter manhole data from the Clark County Water Reclamation District, Las Vegas, Nevada, United States. Since the data were not normally distributed, non-parametric tests were carried out to determine the group differences. The findings showed that the LCC costs of CC manholes, considering both installation and replacement costs, are significantly less than those of PC manholes. However, the differences were not significant for both sizes of pipes when the LCC costs were computed considering the installation costs only. The practical application of this study is that public agencies can employ the CC manholes as the cost-effective option for 60-inch and 48-inch sizes. The results of this study may assist public agencies in choosing cost-effective manhole options in future manhole projects. This study has a limitation in that the findings are directly applicable to 60-inch and 48-inch manholes; public agency engineers should take caution to implement the findings to other sizes.

Keywords Life-Cycle Cost Analysis, Manhole, Cement Concrete, Polymer Concrete

1. Introduction

Wastewater manholes provide access to inspect the state of sewage network systems and are a vital part of the system [1]. Utility professionals can analyze the system's conditions and determine whether it needs repairs or replacement in order to remain safe. A manhole is placed when two or more sewage lines meet, or where a sewer line changes inclination or direction. According to a 2005 survey, there are around twenty million manholes in the United States, of which four million are over 50 years old and five million are between 30 and 50 years old [2]. The average grade given to the United States (US) wastewater systems by the 2021 Infrastructure Report Card [3] is D+, which is in "Poor" condition.

Based on the type of material used, two types of manholes are common for sewer network systems. They are Cement Concrete (CC) and Polymer Concrete (PC) manholes. The CC manholes were primarily utilized by local agencies over the last several decades [4]. Because of the Hydrogen Sulfide (H_2S) produced in the sewer systems, studies have shown that CC manholes are particularly susceptible to chemical corrosion [5-7]. CC manholes are expensive and have unpredictable maintenance and replacement needs as a result of corrosion problems [8]. Chemical attacks have reduced the lifespan of CC manholes, compelling the use of more resilient and economical alternatives. The US Environmental Protection Agency (USEPA) has also strongly encouraged adopting cutting-edge and creative technologies as a solution [9].

In PC, a polymer is used as a binder instead of cement, and aggregates are used as a mineral filler while resins are used as binding agents [10]. Epoxies, saturated polyester, vinyl ester, and methacrylate are the main types of resins utilized. PC is more durable against chemical attacks than cement concrete. However, the kind of resins used determines how they behave [10,11]. Current studies have demonstrated that PC offers advantages over CC that make it more suitable for usage in sewage environments. PC is more expensive than the traditional CC; however, it has higher level of chemical resistance, making it a desirable material in a wastewater environment [12-14].

Inspections are conducted to identify the manholes' state. The frequency of inspection varies from 1-2 years to 10-15 years depending upon the condition of the typical manhole [5]. If the structure is deteriorated, they are repaired using a variety of techniques, including utilization of epoxy and polyurethane, safeguarding against H_2S-induced corrosion, cement-based rejuvenation, utilizing mechanical seals, installation of cast-in-place concrete, application of polymer coatings/linings, implementation of cured-in-place composites, diverse localized repairs, casting of structural lining, deploying cured-in-place lining, incorporating panel liners, and chemical grouting. [5,15-17]. The CC manholes are protected against sulfide corrosion using a number of techniques, including chemical sulfide generation control, sulfide formation prevention design, use of calcareous aggregate, protective coating, and a range of polymeric materials [17]. Because of the corrosion problems, replacement work is frequently done, which increases the manholes' life-cycle costs (LCC). Over the last several decades, a number of alternatives were tested to protect concrete against sulfate corrosion that were not successful [18-20]. Kaushal [21,22] showed that the maintenance and replacement activities also negatively impacted the general public as a result of road closures. In 2019, Kaushal [21] forecasted that there will be significantly more investment required to maintain and replace existing manholes.

In the United States, many cities have replaced CC manholes with PC manholes in the most recent decade, including the Cities of Las Vegas and Austin [23-25]. PC manholes outlast CC manholes by at least 50 years, and they do not require maintenance over their lifespans [12,26,27].

There is no study that compares the costs of the CC and PC manhole options to determine which is the most economical. Therefore, a study of in-depth life-cycle cost analysis is required. In this study, the important goal is to determine the cost-efficient manhole between CCs and PCs. This study's findings may assist public agencies in selecting the most economical manhole option for their upcoming projects.

2. Literature Review

2.1. Corrosion Issues in Traditional Manholes

Khalid and Zayed [1] conducted a study to create a component-based model to assess the wastewater network components' state. The asset's overall state was evaluated by calculating the relative relevance of each component using the analytic network process. The findings demonstrate that, while the partition, seals, and cap and casing were more significant than other components, roots have the biggest influence on many of the components. The model was evaluated using a case study from Edmonton, Canada, and its average validity was 76.24 percent when compared to actual values.

In 2017, Daher et al. [28] carried out an investigation where they investigated the relative importance of imperfections and elements within sewer pipeline segments. The authors evaluated these imperfections using an analytical network process. The sewage systems and infrastructure professionals in Canada and Qatar were surveyed using a questionnaire to assess the relative importance of defects and pipeline components. The section of the pipeline was partitioned into three primary parts: connections, pipe extent, and access points. Each part's imperfections were classified as structural, operational, installation, or replacement issues. The findings indicate that the manhole components had a weight of 0.24 and that the pipeline and joint components each had a weight of 0.38, indicating equal relative importance. Pipeline structural and installation flaws carried a greater relative weight (0.4 and 0.36, respectively) than operational flaws. Joint structural flaws received the highest relative weight (0.61). Defects in manholes have relative weights between 0.3 and 0.4.

In 1988, The American Society of Civil Engineers (ASCE) carried out a study on sulfide in wastewater network systems. Portland cement and rebar are the main components of CC manholes, and both components were vulnerable to sulfuric acid [16]. Two types of aggregates are commonly used in manhole construction, granitic and calcareous. The rate at which concrete manholes deteriorate is influenced by the type of aggregate used. Granitic aggregates are not harmed by sulfuric acid because they are resistant to it, and only the cement bonding can be affected leading to deeper corrosion and exposing fresh cement material. However, when using calcareous aggregates, both the cement and aggregates are damaged by acid, resulting in increased corrosion resistance of CC manhole constructions.

Various studies identified several factors that affect the amount of sulfuric acid production in sewers [5-7]. They were the occurrence of gravity sewer surcharges, sewage with a significant biochemical oxygen demand, prolonged retention periods, the discharge of dissolved oxygen, heightened accumulation of organic solids and grit at the base of the sewer, sewer slopes lacking steepness resulting in reduced flow velocities, and elevated temperatures within the sewage. In 2014, Angkasuwansiri and Sinha [29] developed a wastewater pipe performance rating system to assess defects identified from inspections in wastewater pipe network systems. The rating system evaluates defects by mathematically combining them through a weighted total and a fuzzy interface that considers the factors' significance. In 2005, a study forecasted the condition of pipelines with a data driven approach using artificial neural networks [30]. The model was designed for the City of Atlanta. Utility personnel will use the model to identify the pipelines that need immediate repairs. The overall state of a pipeline can be assessed, the network's weakest links can be found, inspection projects can be prioritized, funding difficulties can be evaluated, and the optimum method for managing subsurface assets can be found. This study identifies that pipeline deterioration can be caused by various factors such as construction defects, external environmental factors, and other factors like age, characteristics, and maintenance methods. The authors studied pipeline deterioration by evaluating seven key factors including pipe material, age, diameter, section length, depth of cover, slope and gradient, and sewer type.

2.2. PC Pipes and Manholes

A study conducted by Beeldens et al. [31] in 2001 incorporated polymers into concrete to increase the lifespan of sewer pipes made of concrete. Eight distinct kinds of polymer emulsions were applied to modify PC while considering curing circumstances and the ratio of polymer to cement. The findings demonstrate that a reduction in porosity typically leads to an improvement in the strength of the mortar modified with polymers. Higher compressive strength was observed to be produced by the traditional 2-day moist curing and the 5-day water curing. Concrete treated with polymers was much less prone to sulfate corrosion than unmodified concrete, according to tests done on the samples using a 0.5 percent sulfuric acid solution.

Ahn et al. [32] investigated PC's physical characteristics (Poisson's coefficient, density, absorption rate, flow, robustness, and Young's modulus, etc.) to determine whether it can be used in manholes in 2009. The average absorption capacity, which was discovered to be 0.39 percent on average and much lower than that of CC, implies enhanced waterproofing properties. PC can be used in manholes close to subsurface water since it has a lower absorption capacity than CC and does not leak like CC does. The study also demonstrated that PC had a higher flexural strength and higher strain than conventional CC. This indicated that PCs are tough, making it the perfect material for manholes.

2.3. Case Studies

Twenty conventional manholes that have deteriorated have been replaced with PC manholes [27]. The design of these new manholes enables connections to pipes of varied lengths, configurations, and positions. The substituted manholes were built with a lower exterior size to fit within the footprints of the old manholes. Without needing extra linings, coatings, or cathodic protection, PC manholes provide long-term resistance to chemical attacks. The study discovered that PC manholes have faster installations over CC manholes, and these newly installed PC manholes are anticipated to last at least 50 years. Studies have revealed that in Austin, Texas, CC manholes had serious corrosion issues [23-25]. PVC liners and various coatings that protect were utilized inside the CC manholes due to the difficulties and cost of repairing them when corroded, but after installation, it was difficult to repair problems with the coating or liner. Therefore, seven Austin Downtown Wastewater project manholes ranging in depth from 70 to 90 feet were selected to be replaced with PC manholes. PC manholes allowed for a significant reduction in the quantity of construction work and accelerated project completion without raising project costs.

2.4. Cost Comparison

Turkey's CC and PC pipe production costs in 2013 were compared in a study carried out by Bozkurt and Islamolu [33]. In their investigation, they considered the cost of labor, raw materials, and overhead. PC pipes were predicted to last 50 years, but CC pipes were predicted to survive 15 years. The study compares the costs of PC and CC pipes with various diameters. Based on market costs, the price of materials for both types of pipes was calculated, and it was anticipated that the labor and overhead costs would be the same for both types. Using the costs per 1000 meters of pipe length throughout the anticipated service life, a cost comparison was done. When only the costs of the raw materials were considered, it was determined that the annual cost of PC pipes was about 120 percent greater than that of CC pipes. However, the annual cost of PC pipes was determined to be 2.50 times more economical than CC pipes due to the lower repair and maintenance expenses when including manufacturing costs over the entire service life. According to the study's findings, using PC pipes results in stronger pipes with longer service lives, less expensive maintenance, and good corrosion resistance.

2.5. Gaps in Literature

Chemical-induced sewer system corrosion is a significant problem that contributes to the deterioration of CC manholes. As a result, the bulk of research concentrated on the features and corrosion of CC manholes, while others concentrate on the advantages and applicability of PC manholes in sewer systems [34,35]. Only a few studies, including Kaushal et al. [22] in 2021 conducted that evaluate open-cut and trenchless replacement techniques for concrete manholes, have been undertaken especially on manhole replacement. Bozkurt and Islamolu [33] in 2013 conducted a different study in which they contrast the production costs of CC and PC sewer pipes, but not manholes. A life-cycle cost (LCC) study has not yet been used to compare these two types of manholes, and a thorough examination of the costs related to these two types is required, which is what this research aims to do.

3. Materials and Methods

The overall research method for this study is demonstrated in Figure 1. There are five key actions. Prior to reviewing the existing literature on CC and PC manholes, the study's objectives and scope were first established. To accomplish the goals, data were gathered, and after that, data analysis was completed. Then, decisions were made. The research approach used for this study is described in depth in the next subsections.

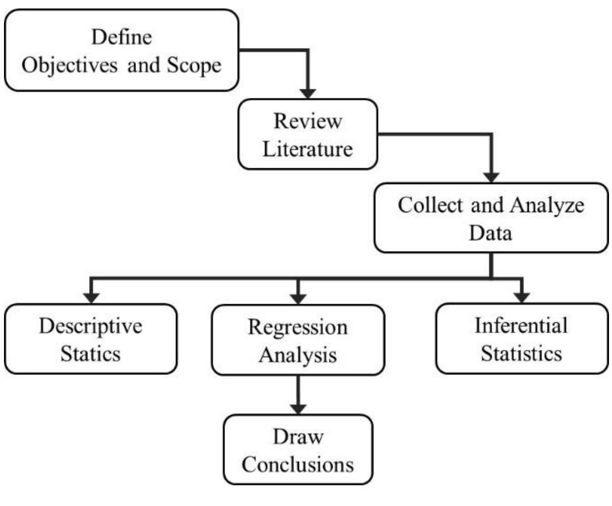

Figure 1. Research Methodology Adopted in This Study

3.1. Research Hypotheses

Four research hypotheses were developed to accomplish the study objectives. They dealt with the cost effectiveness of using two different manhole types. According to the first two research hypotheses, the LCC unit cost of installing 60-inch and 48-inch PC manholes were significantly higher than traditional CC manholes. Another two hypotheses state that the LCC unit cost of combined installation and replacement of 60-inch and 48-inch size PC manholes were significantly higher than that of CC manholes.

3.2. Null Hypotheses

The research hypotheses were transformed into null hypotheses. The null hypotheses state that the LCC unit cost of installing 60-inch and 48-inch PC manholes were less than or equal to that of traditional CC manholes, both in the case of installation cost alone and when the installation costs were combined with replacement costs. Mathematically, they can be expressed as:

$$\mu\_(\text{LCC unit cost of installing 60 inch PC manholes}) \leq \mu\_(\text{LCC unit cost of installing 60 inch CC manholes}) \quad (1)$$

$$\mu\_(\text{LCC unit cost of installing 48 inch PC manholes}) \leq \mu\_(\text{LCC unit cost of installing 48 inch CC manholes}) \quad (2)$$

$$\mu\_(\text{LCC unit cost of install and replace of 60 in PC manholes}) \leq \mu\_(\text{LCC unit cost of install and replace of 60 in CC manholes}) \quad (3)$$

$$\mu\_(\text{LCC unit cost of install and replace of 48 in PC manholes}) \leq \mu\_(\text{LCC unit cost of install and replace of 48 in CC manholes}) \quad (4)$$

3.3. Data Collection

Data on CC and PC manholes were gathered from the Clark County Water Reclamation District (CCWRD), located in Las Vegas, Nevada. The data includes expenditures for the installation and replacement of both types of manholes used in the Las Vegas sewer networks between 1977 and 2017. The data collected also includes information about the physical characteristics of manholes, such as type, depth, unique manhole identification number (ID), etc. Data were electronically exported from their database (called "ProjectView") for the manhole projects completed after 2007. However, data for the projects completed prior to 2007 were gathered from an archive of hard copies (contract agreements, technical specifications, and as-built drawings). Cost data for each new installation and replacement projects were independently gathered for this study. The expenditures for installation and replacement included the cost of labor, materials, equipment, and the cost of other tasks required to complete the manhole project.

The data from CCWRD was then put into a Microsoft Excel spreadsheet. The data indicated that the majority of manholes in the Las Vegas sewer system were CC type, with only a limited PC product. For CC manholes with a 60-inch diameter, there were 454 installations and 248 replacement cost data, while for those with a 48-inch diameter, there were 351 installations and 136 replacement cost data. In the same way, the city had 15 installation and replacement cost data for 48-inch manholes and 20 installation and replacement cost data for 60-inch PC manholes. The information about CC and PC was separated after all the data had been entered into the spreadsheet. For new installation and replacement cost data, different spreadsheets were created to analyze them individually.

3.4. Determining Life-Cycle Costs

The life cycle cost of a manhole refers to the total cost of installation, maintenance, and repair costs to maintain the structure over its entire lifespan. Thus, to calculate the LCC cost, the authors identified the key costs and lifespan of the manholes.

This study collected manhole cost data in the form of dollar cost per manhole. By dividing the cost per manhole by the manhole depths, the unit costs per linear foot of the manholes were calculated. The ENR Construction Cost Index was then used to adjust the manhole unit costs per linear foot for inflation [35]. Costs were adjusted to the base cost in 2022. This manhole cost adjustment was carried out by the following major steps: i) calculating the unit costs of manholes per linear foot, ii) collecting/updating ENR index values, iii) computing index ratios by dividing the 2022 ENR index value by the ENR index value for a particular year, iv) multiplying the unit costs of manholes by the computed index ratios, and v) repeating these above steps for each manhole unit cost to achieve adjustment to the base cost in 2022.

The CC manholes have been in existence since 1977 and have been replaced when needed by their condition assessment. Based on the data, this study calculated the time (in years) between installation and replacement, which is termed as duration for replacement. To determine which manhole was replaced and when, the authors compared unique manhole IDs. After calculating the durations for replacement, the average duration for replacement was determined for CC manholes. Since CCWRD started using polymer concrete in 2015, none of this product has been replaced by the end of 2017. Therefore, the warranty information of PC manholes (50-year service life) was used as the average duration for replacement in this study.

The LCC unit costs for both types of manholes were then computed. Two scenarios were made to calculate the LCC unit costs, considering the installation cost only and then both installation and replacement costs. For the first scenario, the LCC unit costs were calculated using the installation cost per foot and the average duration for replacement by dividing the unit cost of installation per foot by the average duration for replacement. For the second scenario, the unit costs of installation and replacement per foot were added together, and the resulting value was divided by the average duration for replacement.

3.5. Statistical Analysis

To determine whether the data were normally distributed, the Kolmogorov-Sminov and Shapiro-Wilk tests were conducted. The sample population's normal distribution is the null hypothesis. If the p-value is less than 0.05, which indicates that the population of the sample is not normally distributed, then this test rejects the null hypothesis. The group differences are determined by parametric testing if the dataset is normally distributed. Otherwise, non-parametric tests are used to compare the group differences in the manholes LCC unit costs between CC and PC. The null hypothesis for these tests is that there are no statistically significant differences between the median LCC unit costs for CC manholes and PC manholes. The difference between these two groups' median values is considered to be significant if the p-value is less than 0.05. If the p-value is less than 0.01, the difference between these two groups is significant.

4. Results and Discussion

The authors obtained cost per manhole data from CCWRD, Las Vegas. From that data, the manholes' unit costs per linear foot was computed. CC manholes ranged in depth from 3.52 feet to 24.29 feet (median depth 11.77 feet) and PC manholes ranged in depth from 6.44 feet to 13.50 feet (median depth 9.65 feet), respectively. The ENR Construction Cost Index was then used to adjust the manhole unit costs per linear foot for inflation [35]. Costs were adjusted to the base cost in 2022.

To calculate the LCC costs, two key costs were considered. They are installation cost and replacement cost. The replacement cost of 66 CC manholes were obtained from CCWRD; however, some costs were missing in their database. Regression analyses were carried out to estimate the best replacement cost of missing CC manholes for both 60-ich and 48-inch manholes. For the regression analysis, the significant independent variable was found to be the installation cost. Data analysis shows that the replacement year was not a significant independent variable; therefore, this variable was not utilized to predict the replacement cost. Table 1 presents the results of the regression analysis carried out for 60-inch CC manholes. The results show that there is a strong and significant correlation (R = 0.82) between replacement cost and independent variable (installation cost). Based on the regression analysis, equation 5 is created. Using the equation 5, the calculated replacement costs of CC manholes were included in the data analysis. A similar process was carried out for 48-inch manholes as well. The following sub-section provides descriptive information for the LCC of CC and PC manholes.

$$\text{Predicted replacement cost of CC manholes} = 501.40 + 2.125 \times \text{Installation cost} \quad (5)$$

Table 1. Regression Analysis Results for 60-in CC Manholes

Predictor	Coefficients	Standard	T-Stat	P-Value
Intercept	501.40	56.86	8.82	<0.01*
Cost of	2.12	0.19	11.27	<0.01*

Note: *Significant at α level 0.05
Multiple R = 0.82
R-Square = 0.66

4.1. Descriptive Statistics

An overview of descriptive statistics is shown in Table 2. The results show that 60-inch PC type manholes cost more than CC type manholes in both scenarios of LCC unit costs of installation only and LCC unit costs of installation and replacement. The mean and median costs of 60-inch and 48-inch PC manholes are at least nine percent and 26 percent less expensive than CC manholes when installation and restoration LCC unit costs are considered.

4.2. Results of Normality Tests

To determine if the dataset was normally distributed, the Kolmogorov-Smirnov and Shapiro-Wilk normality tests were conducted. The test results are presented in Table 3. The p-values of all the datasets were not more than 0.05, indicating that all the datasets were not normally distributed, so non-parametric tests were carried out to determine if there are significant differences between the groups.

4.3. Results of Mann-Whitney U Tests

This study used non-parametric Mann-Whitney U tests to compare the median LCC unit costs of CC and PC manholes because all the datasets were not normally distributed. The summary of the Mann-Whitney U test results is shown in Table 4. In comparison to PC manholes, there are more CC manholes installed in Las Vegas. The results demonstrate that, when installation costs alone and installation costs and replacement costs are considered, the LCC unit costs of 60-inch and 48-inch PC manholes are higher than those of the CC type. The differences between the two types of manholes are significant for both manhole sizes because the p-values are less than 0.05.

Table 2. Results of Descriptive Statistics

LCC cost	Manhole Size (in.)	Types of Manhole	Sample Size	Mean ($)	Median ($)	Std. Dev. (S)
Installation Costs	60	Cement Concrete	454	47.06	31.65	42.10
		Polymer Concrete	20	48.49	39.47	23.73
	48	Cement Concrete	351	66.77	52.99	51.83
		Polymer Concrete	15	56.86	48.73	21.67
Installation and Replacement Costs	60	Cement Concrete	248	42.56	36.36	22.13
		Polymer Concrete	20	48.49	39.47	23.73
	48	Cement Concrete	136	41.55	38.76	15.62
		Polymer Concrete	15	56.86	48.73	21.67

Table 3. Results of the Kolmogorov-Smirnov and Shapiro–Wilk tests

LCC cost	Manhole Size	Types of Manhole	Kolmogorov-Smirnov		Shapiro-Wilk	
			Statistic	Sig.	Statistic	Sig.
Installation Costs	60	Cement Concrete	0.38	<0.001*	0.49	<0.001*
		Polymer Concrete	0.29	0.002*	0.72	<0.001*
	48	Cement Concrete	0.35	<0.001*	0.44	<0.001*
		Polymer Concrete	0.18	0.20	0.91	0.128
Installation and Replacement Costs	60	Cement Concrete	0.42	<0.001*	0.53	<0.001*
		Polymer Concrete	0.29	0.002*	0.72	<0.001*
	48	Cement Concrete	0.36	<0.001*	0.43	<0.001*
		Polymer Concrete	0.18	0.20	0.91	0.128

Note: * Significant at α level 0.05

Table 4. Results of Mann-Whitney U tests

LCC costs Based on	Manhole Size	Types of Manhole	N	Mean rank	Sig.
Installation Costs Only	60	Cement Concrete	454	235.40	0.11
		Polymer Concrete	20	285.40	
	48	Cement Concrete	351	183.18	0.78
		Polymer Concrete	15	190.90	
Installation and Replacement Costs	60	Cement Concrete	248	131.85	0.04*
		Polymer Concrete	20	167.35	
	48	Cement Concrete	136	72.57	0.01*
		Polymer Concrete	15	107.13	

Note: * Significant at α level 0.05

4.4. Discussion

There are over 20 million of manholes in the United States, and they are a critical component of the sewage network system. Four million manholes needed repair or replacement because of their poor condition [2]. While PC manholes are relatively new, CC manholes have been in use for decades. Based on two scenarios, installation costs alone and installation costs together with replacement, this study determined the LCC unit costs of these two types of manholes, consisting of 474 manholes (454 CC manholes and 20 PC manholes).

When manholes were in deteriorated conditions, the CCWRD replaced them as needed. In this study, the data collected showed that the median installation and replacement LCC costs for 60-inch and 48-inch CC manholes in 2022 were $31.65 and $36.36 (60-inch) and $52.99 and $38.76 (48-inch), respectively. In comparison to new installment costs, the replacement cost of 60-inch manholes were 15 percent higher, and that of 48-inch manholes were 37 percent lower. One of the primary causes of higher replacement costs of 60-inch CC manholes compared to new installation costs is that contractors must perform additional preparation works prior to replacement, such as cleaning the manhole surface, removing debris, and managing any existing sewage [15]. Depending on the type of replacement system used, additional tests are required for quality control. Additional safety procedures are also required in the sewer environment to safeguard professionals. The scope of work may also be a factor in contractor bid costs [36,37]. These considerations may account for the higher replacement costs of the CC manholes.

The average duration for replacement (CC manhole) was computed as 23 years. Two studies used a similar methodology to determine the typical frequency of chip sealing and striping activities [38,39]. For PC manholes, this study used the manufacturer's warranty duration (50-years) to calculate the LCC costs; other studies also considered the same [12,26,27]. The LCC unit costs for CC manholes were determined in two scenarios, one that only took installation costs into account and another that took installation and replacement costs into account. When installation costs alone were considered, the LCC unit cost of the CC manholes was determined by dividing unit installation costs by the average duration for replacement. A similar process was used for the PC manholes as well.

The study's results show that the LCC unit installation cost of PC manholes and the product life were higher than that of traditional CC manholes. This means that CC manholes have a lower initial cost with a shorter service life. One of the key reasons for the shorter life of CC manholes is the corrosive sewage environment [8]. The study shows that installing a PC manhole costs more than installing a CC type manhole. Comparatively, PC manholes have higher upfront costs. This may be because the production cost per unit of PC manhole is higher than the cost per unit of a traditional CC. Bozkurt and Islamoglu [33] demonstrated that the cost of producing a PC was 20 percent more than that of a traditional CC. Another reason may be the increased overhead cost of PC products due to the limited usage of PC products or the scale factor. The LCC installation cost of CC manholes is less than the PC manholes; however, there is no significant difference between them.

In the second scenario, when LCC costs were calculated considering both the installation and replacement, the entire service life of CC manholes became 46 years. The PC manholes have not been replaced since 2015; thus, in the second scenario, this study uses the LCC cost of a PC manhole considering installation cost only. The second scenario provides a more holistic outcome of the study findings. The LCC unit cost analysis revealed that the combined LCC unit cost of CC is significantly lower than the same PC manhole costs. The LCC unit cost of PC manholes was nine percent higher for 60-inch manholes and 31 percent higher for 48-inch manholes. This is due to the fact that PC manholes were much more expensive than CC manholes. CC and PC manholes have an average lifespan of 23 and 50 years, respectively. CC manholes have a much shorter lifespan than other CC constructions. This could be a result of the sewage environment. Chemical attacks cause the life of CC manholes to be short and costly; they have a history of inconsistent and disruptive maintenance needs [8]. The CC manhole dataset has a lower standard deviation than the PC type. This might be because CC manholes have been utilized for longer periods of time than PC manholes. Contractors may also have more confidence with their bid costs. Other studies found that, when using new contracts or a new form of construction, the unit cost increased.

LeBlanc [27] revealed that utilizing PC manholes offers economic advantages as well as scheduling advantages. Installing PC manholes required less time than installing cast-in-place CC manholes because PC manholes do not require curing (at site) and the installation of a corrosion-resistant coating. They do not need other testing, such as spark tests, and for traffic control, PC manhole installation takes significantly less time. Additionally, there are more benefits, including a reduced impact on the public and environmental benefits [30,40]. Other studies also developed a framework for cost efficiency of roadway infrastructures [41].

4.5. Limitations

Although manholes are a main element of a sewage system, few studies address them. The number of PC manhole data samples for this study is limited, as its upfront installation cost is much higher due to the use of a newer material. Since PC manholes have been in use in Las Vegas since 2015, there is no documentation of how frequently the product is replaced; as a result, the study findings were based on the warranty period of the product, which is 50 years. The study's conclusions are only applicable to manholes with a 60-inch and 48-inch diameter, since other sizes could not be evaluated due to a lack of data for statistical analysis.

5. Conclusions and Recommendations

Manholes are an essential part of a city sewage line network system. They are used to gain access to and maintain the performance of the wastewater sewage systems. In the United States, there are over 20 million manholes, and more than 25 percent of them require repair or replacement to remain in functioning condition [2]. Concrete manholes typically come in two varieties: Cement Concrete (CC) and Polymer Concrete (PC). The main goal of this study is to investigate the most cost-effective alternative with regard to these options utilizing Life-Cycle Cost (LCC) analysis.

To accomplish this goal, information on manhole data from the Clark County Water Reclamation District (CCWRD) of Las Vegas, was gathered during a 40-year period (from 1977 to 2017). The data for PC manholes, however, were only available from 2015 to 2017. The analysis includes 454 CC manholes (60 inch in diameter), 20 PC manholes (60 inch in diameter), 351 CC manholes (48-inch), and 15 PC manholes (48-inch). The information gathered includes dates for installation and replacement, information about manholes' physical properties (such as their diameter, depth, type, and unique identification number), and cost data (original installation costs and replacement costs).

The average duration of replacing CC manholes was calculated as 23 years, meaning that the CC manholes had an average lifespan of 23 years. Regarding the PC, the installed manholes were not replaced until the end of 2017 because, according to the manufacturing guarantee term, they have a service life of 50 years. PC manholes were recently introduced in 2015 in Las Vegas. As a result, 50 years was chosen as the product's service life. Other studies also consider the polymer concrete product's service life as 50 years [12,33].

When the average installation and replacement costs of CC manholes are examined, the data reveals that the median installation and replacement LCC costs (in 2022) were $31.65 and $36.36 (60-inch), and $52.99 and $38.76 (48-inch), respectively. The replacement cost of a 60-inch manhole was 15 percent higher, and the replacement cost of a 48-inch manhole was 37 percent less compared to their respective installation costs. When the median installation costs of 60-inch CC and PC manholes are compared, the installation cost of PC manholes was 25 percent higher than the CC manholes. Similarly, when LCC costs address both installation and replacement costs, PC manholes are nine percent (60-inch) and 26 percent (48-inch) higher compared to CC manholes. This shows that PC manholes are more expensive up front than the traditional CC manholes. Because the data were not normally distributed, a non-parametric test, the Mann Whitney U tests, were used to compare the LCC cost of CC and PC manholes. The test results demonstrate that, in scenario one, when only installation costs are considered, the LCC cost of CC manholes was less than PC manholes (for both 60-inch and 48-inch); however, the difference is not significant. In scenario two, when both installation and replacement costs were considered, the LCC unit costs of CC manholes are significantly lower than that of the PC manholes for both sizes. Because this study only examines data from 60-inch and 48-inch diameter manholes, its conclusions cannot be generalized, and public agencies should use caution when applying its findings to other types of manholes.

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