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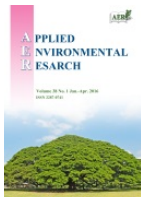

Inspection and Understanding of Sewer Network Condition in Dindaeng District (Thailand)

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Abstract

Sewer pipelines are usually operated with little maintenance after installation. After years in service, sewer pipes get old and deteriorated. The present research is the first study that attempts to inspect the condition of sewer pipelines in the Bangkok Metropolitan Area. A robot with Closed Circuit Television (CCTV) was used to capture videos and images of the interior of the sewer pipelines between two manholes. The system was operated by Utility Business Alliance (UBA) Company. The condition of the sewer pipelines was visually analyzed in line with the scoring and grading system of New Zealand's pipe inspection manual. CCTV footage was received from UBA, and each meter of the sewer pipelines was visually inspected, scored, and graded. The study area included 22 randomly selected roads around Dindaeng District. For the structural condition, surface damage was found in all of the 89 inspected pipes. Joint faulty and crack longitudinal were found in approximately 60% of the inspected sewer pipelines. Infiltration present was found in 33% of the inspected pipes, while crack circumferential and crack multiple were minimal in the study area. For the service condition, obstruction temporary, debris silty, and debris greasy were found in 15%, 11%, and 4% of the inspected sewer pipelines, respectively. The grades of the structural condition were mainly between 4 and 5, indicating that most of the sewer pipelines in the area would need rehabilitation programs. The grades of the service condition were between excellent and good. This is the first time that such a program has been conducted in Thailand. The information of the condition of the pipelines and the inspection and characterization methods should be used as a reference for maintenance programs and future assessment programs. The adjustment or development of the inspection manual should be done in collaboration with local contacts.

Keywords: Sewer pipeline; Assessment of pipe condition; Scoring system; Grading system; Defect types

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Introduction

In Thailand, wastewater is one of the major environmental problems. There are two main sources of wastewater: the community and the industrial sector. The estimated discharge of wastewater from the community is 14 million cubic meters per day. The district administrations, the 1,687 municipalities, and the combination of the Bangkok Metropolitan Administration (BMA) and Pattaya City discharge 9 million, 2.5 million, and 2.5 million cubic meters of wastewater per day, respectively [1].

The sewage collection system of the BMA is a combined sewage system (i.e., a combination of wastewater and stormwater). The interceptor chamber is used for the collection of all wastewater and the transport of it to wastewater treatment plants (WWTPs). During the wet season, the wastewater is five times higher than that of the dry season because of the combination of wastewater and stormwater. In this case, the combined wastewater is transported and treated at WWTPs. The excess wastewater is discharged into canals or rivers after the screening stage. For the BMA, there are more than 1,000 interceptor chambers in the system.

The sewer systems and the interceptor chambers are relatively old with little maintenance [2]. In many countries, rehabilitation, replacement, and upgrading programs for public sewer systems are needed, and the costs of such programs are very high [3–4].

This research is the first investigation of the condition of Bangkok's sewer system, and the results can be used as guidance for maintenance, rehabilitation programs, and schedules (budget management) of the BMA's sewer system.

Background

Located in the Bangkok Metropolitan Area, Dindaeng Water Environment Control Plant is a large treatment plant, which started operations in 2004. The treatment area of the plant is 37 km^2, and the plant site area is 27,200 m^2. The sewer collection pipe is 64 km long. The plant is a wastewater collection and treatment system. The wastewater treatment system includes screening, grit chambers, and activated sludge with nutrient removal and clarification. According to the design of the plant, the wastewater from eight districts (population of 1.08 million) is collected and treated. The plant's treatment capacity of wastewater is 350,000 cubic meters per day. In total, 95% of the treated wastewater is released through seven canals into the Chao Phraya River, the Sam Sen Klong, and the Makkasan Ponds. The remainder of the treated wastewater (5%) is reused for gardening, irrigation, and other purposes by the municipality [5]. In the populous areas of Bangkok, the amount of wastewater that is collected is greater than in the other areas, and any damage to sewer pipes may have a larger negative effect than in the other areas of the city. Therefore, the inspection of the condition of wastewater collection pipes is needed to reduce the costs of repairing the physical damage done to pipes, to reduce the costs of maintenance programs, and to prevent the contamination of the environment and people's health. Many techniques have been developed for the inspection of underground pipelines, such as visual/person inspection, Closed Circuit Television (CCTV), sonar/CCTV [6], dye testing, zoom camera technology, Sewer Scanners and Evaluation Technology (SSET), Ground Penetration Rader (GPR), ultrasonic inspection (sonar), impulse hammer, smoke testing [7], acoustic sensors, electrical/electromagnetic, laser profiling, infrared thermography [8], flow rate measurement [9], stable isotopes method [10], and pollutant time series method [11]. A summary of the underground pipeline inspection methods and the corresponding advantages are presented in Supplementary Material (SM) 1.

The advanced technologies for the inspection of sewer systems include sonar-based and laser-based scanning, digital side scanners, and ground penetrating radar [12-15]. However, there are some limitations for these technologies. Therefore, CCTV is wildly used in the inspection of sewer pipes in wastewater collection systems because it can be applied in many condition [16]. It can detect the cracked areas of pipes and plant root penetration into the pipes, which causes breaks in pipes and improper connections. These are the sources of infiltration [11]. This method provides important information for the rehabilitation of pipes. Hence, CCTV inspection is an effective technique for the inspection of active pipes. However, it is an expensive method, and it cannot detect inactive taps and illicit discharge from households. It also takes time to analyze the results.

Although the inspection of sewer with CCTV has been primarily used in North America for over 40 years, several advanced technologies for the inspection of sewer systems have been rapidly developed over the last two decades [17-19]. Some of the advantages of CCTV inspection are that laborers can avoid hazardous areas and the process is less time consuming, so it can be utilized regularly. The shape and the size of the robot determines its maneuverability. The inspection of pipes with robots is used in various fields, such as the electric, gas, hydro, nuclear and fossil fuel fields. The condition of the pipes needs to be assessed because pipes can be damaged by vibration, shock loading, thermal cycling, corrosion, cracking, pitting, joint faulty, etc.

The first methodology of sewer pipe inspection was proposed for the identification and extraction of a set of video segments, called the Regions of Interest (ROI), which focus mainly on defective areas, corrosion, connections of pipes, deposits, roots, and holes [16]. The extraction of ROI highly depends on the operator who controls the sequence of camera motions. This method is an indirect method for inspecting ROI. The camera can capture the location and the serious areas of ROI that catch the operator's attention. Therefore, the inspection quality and the information of the assessment condition largely depend on the experience and the skill level of the operator [20], the resolution of the image, and the flow level of the water [8]. CCTV guidelines and requirements of detailed sewer pipe inspection depend on the standards set by each country. In general, the inspection of sewer pipes by CCTV starts with the cleaning process to remove unrequired objects that accumulate, such as grit, grease, and debris. The next step is the inspection of the sewer pipeline by CCTV. The requirements are a video camera (pan and tilt) with 360*270 degree rotation, illumination sensitivity 3 lux or less and 460 resolution, lighting intensity adjustment, and a camera speed that depends on the diameter of the pipe. For CCTV, the forward-looking pan, the tilt, and the zoom camera, which are affixed to a robot crawler, are operated by remote control. The robot crawler can travel along from manhole to manhole [20]. Generally, the screening header provides: (1) survey by (contractor name), (2) city/street, (3) location code, (4) direction of inspection, (5) pipe material, (6) diameter of pipe, (7) pipe length (distance of inspection), (8) start manhole, (9) end manhole, (10) pipe ID/MH code, (11) inspection time/date, etc. The running screen (during the pipe inspection) shows: (1) city/street, (2) manhole number (start/end), (3) direction of inspection, (4) inspection time/date, and (5) running total (distance of camera from MH start) [21–23]. Typically, during CCTV inspection, the camera moves forward down the axis of the sewer pipe at a speed of 2.0–5.0 m min^{-1}. Depending on the characteristics of the sewer pipe, like the cleanliness and the pipe diameter, this method can also detect defects and cracks. The operator can control the camera's forward-backward motion, speed, pause, pan, and tilt, and the image can be recorded in order to detect ROI [24]. During the inspection, the operator can stop and check/zoom when a region of interest is seen. The flow level during the inspection should be less than 25% in general. After inspection by CCTV, the required data, which include video recordings, DVDs, photographs, and defect codes, are evaluated in order to determine the condition grade of the sewer pipes. It is important that the database includes the correct assessment number on the CCTV header for future reference [21, 23, 25]. Then, the inspectors check the ROI in the pipes in a discontinuous manner (stop and check) from the recorded CCTV footage [26]. The CCTV software tools support the detection of defects using real-time feedback. The multi-sensor inspection robots can acquire data by automatic processing, fusing, and interpretation, in order to build a complete picture of the sewer pipe conditions [27]. The pipe condition assessment is based on the visual inspection of CCTV to establish the standard protocols [28]. The assessment is useful for avoiding expensive repair costs, managing budget allocations, protecting public health, and preventing environmental contamination, such as flooding.

In Thailand, guidelines or manuals for sewer maintenance that are based on the condition of sewer pipelines have not yet been developed. There are numerous guidelines and manuals already developed in many countries, especially in European countries [6, 18, 19, 21, 29–33]. The present study is the first step for the condition assessment of Bangkok's sewer pipelines in order to develop national guidelines. It is based on the existing New Zealand Pipe Inspection Manual.

In the New Zealand manual, the severity codes are defined as their related scores, depending on the severity level [21]. Then, the severity types and codes are defined by their local codes. In this research, the coding and grading system follows the New Zealand standard. Likewise, the condition assessment of Bangkok's sewer pipelines is adapted from the methods used in the New Zealand Pipe Inspection Manual.

The New Zealand Pipe Inspection Manual is compatible with the European coding system. The manual provides samples of photos and clear descriptions that are easy to match with the results for this study. The New Zealand Gravity Pipe Inspection Manual (4th edition) was released in 2019 with more details on defect codes, scoring systems, and grading systems [34]. However, in the present research, the New Zealand Pipe Inspection Manual (3rd edition) is followed as this is the first attempt at the inspection of Bangkok's sewer pipeline system. The explanation of the scoring system and grading system from the manual are discussed in the following section.

1) The scoring system for structural conditions

The two types of condition scores, namely the structural condition scores and service condition scores, are analyzed separately. The structural condition score is composed of 20 defect codes. Each criterion of the 20 defect codes has its own severity level rating, which is based on the severity codes: small (S), medium (M), and large (L). The severity code "S" is given when the score is less than 10 points, and the sewer pipes can be used for more than 10 years. The severity code "M" is for a score that is between 10 and 25 points, and the severity code "L" is for a score of 30 points and above. The 20 defect codes and the condition rating scores are explained in SM 2.

2) The grading system for scoring

In the grading system for each condition (i.e., for both the structural and the service conditions), there are two types of scores: the peak score and the mean score. The peak scores indicate the worst parts of the sewer pipelines, which need to be prioritized for rehabilitation. The mean score shows the overall condition of the sewer pipeline. Rehabilitation, system upgrades, and cleaning of the pipeline are considered based upon the scores. First, every meter of the pipelines is analyzed by CCTV video footage, and scores are given for any defective conditions found. Then, all the scores are integrated and divided by the length of the sewer pipeline to find the mean score, as shown in Eq 1. The peak scores are remarkable for the worst damage point in each sewer pipe segment.

Five grades are assigned based on the severity score of the defects for both the structure and the service condition of the sewer pipeline. However, both grading systems use different score ranges, as shown in SM 3. In this research, the descriptions that were commonly found for the structural conditions of Dindaeng's sewer collection pipes are mentioned.

3) Description of common defects for structural conditions in Dindaeng District

"Crack longitudinal (CL)" means the crack is located longitudinally on the surface of the pipeline. If the crack appears as a hairline, the "S" code is given. If the crack is open, but there is no evidence of staining on the wall or infiltration, the pipe is given the "M" code. However, if there is evidence of cracks through to the outside of the wall and staining on the wall or infiltration, the pipe is given the "L" code. In this research, "crack longitudinal" refers to a crack that is located in a parallel position to the sewer pipeline.

"Infiltration present (IP)" means water from outside has infiltrated the sewer pipe's walls or joints. There are also three stages of the score for infiltration present (IP). The small code (score 2) means that there is a wet area at the joint. The medium code (score 15) means that there is a running flow through the joint. The large code (score 30) means that there is significant infiltration flow. In this research, most of the infiltration occurred at the joints. Therefore, the score was given depending on the severity level of the infiltration, while the category of the joint faulty was considered separately.

The evaluation of joint faulty (JF) is based on the damage in the joints, such as sealing defects, open joints, and infiltration. The damage is assigned in the joints. If the sealing of the joint is spared or there are minor defects in the joints, the score is assigned under joint faulty. In the present research, infiltration present (IP) and joint faulty (JF) were found largely at the same location.

Surface damage (SD) may be caused by chemical or microbial corrosion. As a result, the surfaces of pipes are damaged, spalled, or aggressed. In this research, minor damage on the surface, aggressive cases, and major damage of the surface were found in the study area.

4) The scoring system for service condition

Service condition scores include five defect codes. These codes have their own scores, which are similar to the structural condition scores, and they are summarized in SM 4. The grading system for service also follows the system of structural condition and is summarized in SM 5.

5) Description of common service condition defects in Dindaeng District

In the service condition of the pipelines, three kinds of defects, including obstruction temporary (OT), debris silty (DE), and debris greasy (DG), were observed in this research. "Obstruction temporary" means that an object is temporarily blocking the pipeline; it should be removed during the cleaning process. In this research, the pipe gets the small code (score 8) if there is wood lay on the cross section of the pipelines. The medium code (score 20) is given if there is stone lay in the middle of the sewer flow.

$$\text{Severity Mean Score} = \frac{\text{Sum of individual defect scores}}{\text{Total length of pipeline}} \quad \text{(Eq.1)}$$

"Debris silty" is defined as the deposit of silt at the bottom of the sewer pipe. In this research, minor deposits were found at the bottom of the pipelines. Therefore, the related scores were assigned.

"Debris greasy" means that grease, fat, or oil is attached to the wall. In this study, only minor cases of DG were observed, and they were scored as small (score 8).

The purpose of this research is to assess the condition of the wastewater collection pipelines in Bangkok and to develop national guidelines for sewer pipe inspection, operations, and maintenance programs in the future.

Material and methods

This research includes two parts: data collection by a robot with CCTV and data analysis. For the data collection, which was conducted by UBA Company, the condition of the sewer pipes was recorded by a robot mounted with CCTV. The robot ran along the sewer pipelines and recorded videos and images of the condition of the pipes between manholes. The UBA staff monitored and controlled the robot with CCTV at a ground station. The study outline is shown in Figure 1.

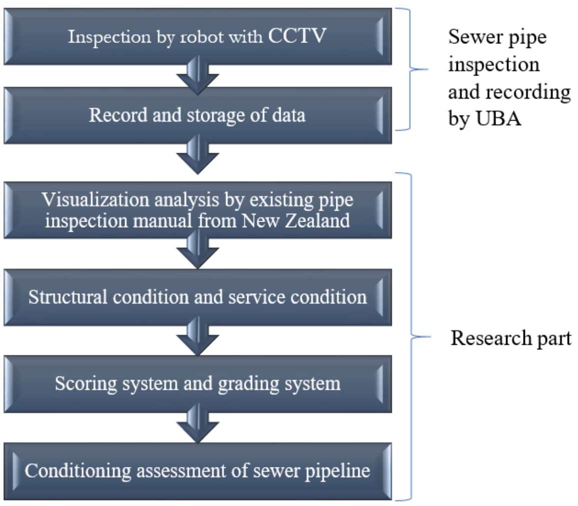

Figure 1 Outline of research work.

In this research, the recorded CCTV footage for sewer pipelines with a length of 5876.35 meters was received from UBA. It was then inspected, characterized, and classified in order to determine the condition of the sewer pipelines by visual inspection.

1) Study area

The present study covered 5,876.35 m of randomly selected sewers with various pipe diameters (450, 500, 560, 600, 800, and 1000 mm) in Dindaeng District, Bangkok, Thailand. A total of 89 pipelines under 22 roads were randomly analyzed in this study. Table 1 summarizes the details of the inspected sewer pipelines.

2) Sewer pipe inspection by UBA

In this study, the pre-cleaning process was done to remove grit, grease, and garbage. In the inspection of the sewer pipes, a pan and tilt camera was used with 360*270 degrees rotation. The image sensor was 1/4 Sony CCD, the resolution was 540 TVL, and the illumination was 0.01 LUX. It included 120 times auto focus and an ultra-bright, dimmable LED light as the light source. The speed of the video recording was approximately six seconds/meter.

The following details were documented at the beginning of each survey (on the screening header): survey date and time, location of the sewer pipeline, sewer ID, reference number, manhole ID, pipe type, pipe diameter, contractor, operator, flow direction, distance, slope, and speed of the robot. During the whole inspection process, the running screen text displayed the location of the pipe, slope, speed, distance, and inspection date and time. At the end of the survey, the following information was presented: date and time, manhole ID, location of the sewer pipeline, sewer ID, reference number, contractor, slope, speed, and distance.

Figure 2 and 3 illustrate the inspection of the sewer pipeline by UBA Group and the screen header text of the sewer pipe. The detail of the components of the robot crawler with CCTV is provided in SM 6.

Table 1 Detailed data for inspected sewer pipelines

No.	Road	Inspected total number of pipes	Inspected total number of manholes	Inspected total pipe length (m)
1	Samsen	14	17	745
2	Klong Samsen	4	7	240.18
3	Kheow-khai-ka	5	6	224
4	Nakorn Chai Si	5	6	367
5	Boripat	4	6	272.75
6	Supan	3	4	131
7	Lukluang	5	7	427
8	Vibhavadi Rangsit	11	15	766.16
9	Asok-Dindeang	4	7	261
10	Klong Huaykhwang	6	7	240
11	Ratchadaphisek	3	5	230
12	Sukhothai	3	4	183
13	Soi Pracha Songkhro	2	4	282
14	Klong Nasong	2	4	179
15	Ratchadapisek 3	2	3	154.87
16	Klong Prem Prachakorn,	2	3	90.56
17	Rama 6	4	8	276
18	Ratchsima	2	3	146.83
19	Krung Kasem	3	6	286
20	Soi Phophan Dindaeng	1	2	106
21	Nakhon Pathom	3	4	164
22	Yaowarat	1	2	104
	Total	89	130	5876.35

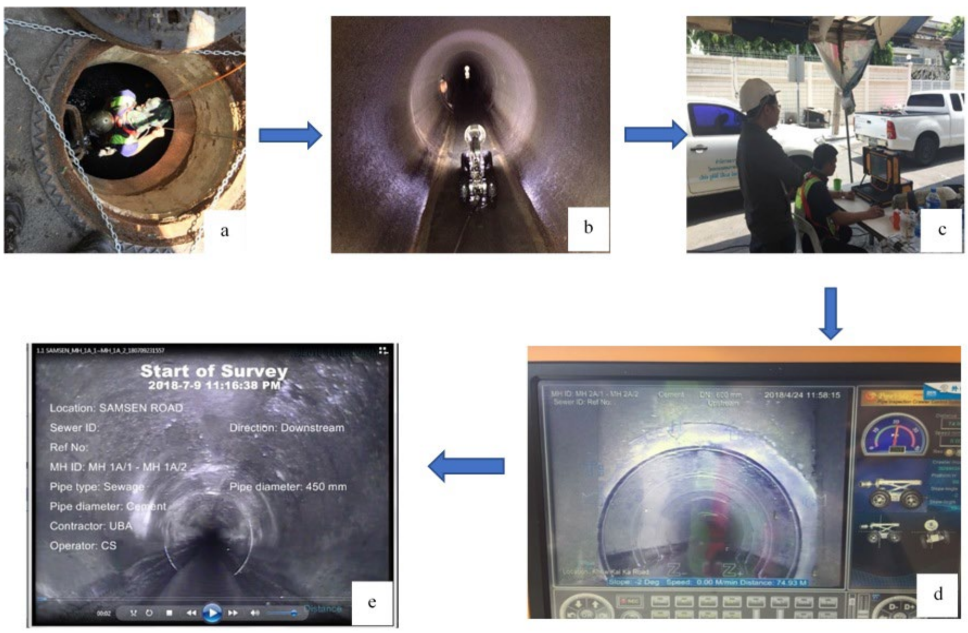

Figure 2 Survey of sewer pipelines by the robot crawler with CCTV of (a) staff placing the robot, (b) running the robot from manhole to manhole [46], (c) the control center, (d) display screen and (e) video footage.

Figure 3 Data shown on the screen of the recorded video.

3) The condition of the sewer collection pipe assessment

The recorded CCTV footage was received from UBA for the inspection of the sewer pipes' condition. The characterization and the classification of the sewer pipes' defects and damages were analyzed by visual inspection based on the New Zealand Pipe Inspection Manual [21]. In this study, every meter of the sewer pipeline was inspected. The characterization of the sewer pipes was categorized into 25 defect codes: 20 condition codes and five service codes. The calculation of the grading system used Eq. 1. The sewer pipes were classified into five grades that were based on the scores of the defect codes: grade 1 (excellent), grade 2 (good), grade 3 (moderate), grade 4 (poor), and grade 5 (fail). There are five grading thresholds that can be achieved as a result of the severity scores.

Results and discussion

The study's findings of the structural condition of the sewer pipelines indicate that the most common defect code was surface damage. In fact, surface damage was found in all of the 89 pipes inspected at the 22 roads. Small severity levels were found at only eight of the 22 roads. Three roads, namely Ratchadapisek 3, Ratchasima, and Soi Phophan Dindaeng, were observed to have the middle level of severity. Ten roads had both the small and the medium level of severity. Furthermore, large severity levels were found at three roads: Samsen (7%), Vibhavadi Rangsit (36%), and Krung Kasem (33%). The corrosion of sewer pipes may be caused by the low velocity of wastewater, deposits, inadequate slope, and low-quality concrete [35–36]. Joint faulty was found at 14 roads. Among them, eight roads, namely Khaeo-Kai-Ka, Nakorn Chai Si, Asoke-Dingdaeng, Klong Huakwang, Rama 6, Ratchasima, Soi Phophan Dindaeng, and Nakhon Pathom, reached 100% of the defect severity level. The majority of the roads had defects of the small level of severity, except for Samsen Road, which indicated the middle level of severity (7%). Crack longitudinal defects were found at 18 roads. Six of the 18 roads, namely Asoke-Dindaeng, Soi Pracha Songkhro, Ratchasima, Soi Phophan Dindaeng, Nakhon Pathom, and Yaowarat, indicated defects at 100% of the small severity level. Infiltration present was found in 10 of the 22 roads. In this case, Ratchasima and Nakhon Pathom were also found to have defects at 100% of the small severity level. Crack circumferential was found at Samsen Road (7% of the small severity level) and Lukluang Road (40% of the small severity level). Kuliczkowaska E. (2013) suggested that inadequate pipe depth or destabilization of the ground is the cause of crack circumferential [35]. Crack multiple was found at Rama 6 Road. This may be due to the mechanical impact from the installation of the pipe and tension surrounding the pipe [35, 37]. However, crack multiple was minimal in the study area. All the common defect codes, such as CL, IP, JF, and SD, were found at Ratchasima Road and Nakhon Pathom Road at 100%.

Crack longitudinal is mainly caused by stress from external loading, inadequate pipe depth, and reduced pipe strength, which is brought on by pipe corrosion or surface damage [35]. Angkasuwansiri et al. (2013) reported that infiltration and inflow may be caused by soil erosion and increases in the volume of sewer flow [36].

Ye et al. (2018) studied the diagnosis of most structure defect types, such as deformation of sewer pipes, joint defects (displaced/damage), and infiltration. These defect types were chosen for the image recognition process of sewer pipes in China [38]. Shin et al. (2016) reported on the comparison of the existing protocol, MOE (adapted from the New Zealand Pipe Inspection Manual and WRCs), and the extended protocol called SCARD. The result found crack longitudinal (19%), crack circumferential (6.3%), crack multiple (0.4%), infiltration (2.1%), joint faulty (19.2%), and surface damage (7.4%) [39]. Daher et al. (2018) observed that high weights of structural defects, such as crack multiple, collapsed sewer pipes, corroded reinforced concrete pipes, and defective joints [40]. Kaddoura et al. (2018) studied deformation and surface damage to assess sewer pipe defects. Utilized in the decision-making process was the Multiattribute Utility Theory, which was based on various protocols and guide-lines, including the New Zealand Pipe Inspection Manual [22].

Regarding the structural condition of this research, the majority of the findings were SD defects, while the second most common defect type was JF. The next most common defects were CL, IP, CC, and CM. The mean score for the structural condition of the sewer pipelines was mainly between grade 4 and 5. The peak scores of the sewer pipelines were divided into two large groups: good-moderate (grade 2-3) and moderate-fail (grade 3-5). According to the New Zealand Pipe Inspection Manual, grade 5 pipes should be considered for immediate maintenance programs because it indicates that the pipe has collapsed or broken. However, in this study, grade 5 does not indicate that. Most of the scores are dominated by the score of the sewer pipe damage. The sample pictures of pipe conditions in Dindaeng District are provided in SM 7. If the whole pipe is damaged by one or more defects between two manholes, and a score is given for the pipe, it will be given a grade based on the average of the various defect scores. Table 2 show the structural condition of the sewer pipelines in Dindaeng District.

Since this is the first attempt to study the condition of the sewer pipelines in Thailand, the scoring system and grading system from New Zealand's pipe inspection manual may not be fully applicable to the Thai system. For example, the pipe condition, specification, and installation standards may not be exactly the same as in the manual. However, this study provides information in the local context for assessment and manual development in the future.

Regarding the service condition of the pipelines, the defect of obstruction temporary was found in eight of the 22 roads. Among them, Boripat Road showed the highest percentage of defects at the small severity level. Debris silty was found at five roads. Soi Pracha Songkhro and Soi Phophan Dindaeng contained defects at 100% of the small severity level. Angkasuwansiri et al. (2013) reported that deposits may happen due to an inadequate slope and low velocities of sewer flow in sewer pipelines [36, 41-43]. Debris greasy was found in four roads. Soi Phophan Dindaeng indicated defects at 100% of the small severity level. Fat, oil, and grease are usually discharged from both residential and industrial areas, like poultry industries [41, 44-45]. Most of the pipelines in the study area received an excellent to good grade for the service condition. Therefore, Soi Pracha Songkhro and Soi Phophan Dindaeng should be considered as the two top priorities for maintenance programs. The detailed information is summarized in Table 3.

Table 1 Structural condition of sewer pipelines in Dindaeng District

No.	Road	CC		CL		CM		IP		JF			SD				Grade for structure	
		% Total	% of Small	% Total	% of Small	% Total	%of Small	% Total	% of Small	% Total	% of Small	% of Medium	% Total	% of Small	% of Medium	% of Large	Peak score	Mean score
1	Samsen	7	7	64	64			64	64	86	79	7	100	79	14	7	2-5.8	4.6-5.2
2	Klong Samsen			75	75			75	75	75	75		100	100			2-4.8	5
3	Khaeo-kai-ka			60	60			40	40	100	100		100	60	40		3-5.8	2-5.2
4	Nakhon Chai Si			80	80			60	60	100	100		100	40	60		5-5.8	5-5.2
5	Boripat												100	100			2-3	4.8-5
6	Supan			67	67					67	67		100	67	33		5-5.2	5
7	Lukluang	40	40	80	80			60	60	60	60		100	60	40		2-5.8	5-5.2
8	Vibhavadi Rangsit			27	27					18	18		100	18	45	36	2-5.2	5-5.4
9	Asoke-Dindaeng			100	100					100	100		100	100			2-5.2	5
10	Klong Huakwang			67	67			33	33	100	100		100	83	17		2-5	4.8-5
11	Ratchadapisek												100	100			2	4.8-5
12	Sukhothai												100	100			2-3	4-5
13	Soi Pracha Songkhro			100	100			50	50	50	50		100	50	50		3.4-4.4	5
14	Klong Nasong			50	50								100	50	50		2-3.4	4.8-5
15	Ratchadapisek 3												100		100		3-3.4	5
16	Klong Prem Prachakorn			50	50								100	100			2-3	5
17	Rama 6			50	50	25	25	25	25	100	100		100	75	25		2-5.6	4-5
18	Ratchasima			100	100			100	100	100	100		100		100		5.6-5.8	5
19	Krung Kasem			67	67								100	33	33	33	2-5.2	4.2-5
20	Soi Phophan Dindaeng			100	100					100	100		100		100		5.6	5
21	Nakhon Pathom			100	100			100	100	100	100		100	100			5-5.4	5
22	Yaowarat			100	100								100	100			2	4.8

Remark: $\%\ damage = \frac{Number\ of\ pipe\ sections\ with\ observed\ damages}{Total\ number\ of\ pipe\ sections\ inspected} \times 100$

Table 3 Service condition of sewer pipelines in Dindaeng District

No.	Road	OT		DE		DG		Grade for service	
		% total	% of small	% total	% of small	% total	% of small	Peak score	Mean score
1	Samsen	29	29					1-3	1
2	Klong Samsen							1	1
3	Khaeo-kai-ka	20	20					1-2	1
4	Nakhon Chai Si							1	1
5	Boripat	75	75					1-4.2	1-2
6	Supan			33	33			1-3	1-2
7	Lukluang	20	20					1-4.2	1
8	Vibhavadi Rangsit	9	9	45	45	9	9	1-4	1-5.8
9	Asoke-Dindaeng							1	1
10	Klong Huakwang							1	1
11	Ratchadapisek							1	1
12	Sukhothai							1	1
13	Soi Pracha Songkhro	50	50	100	50	50	50	3-4.2	1-5.6
14	Klong Nasong							1	1
15	Ratchadapisek 3	50	50					1-3	1
16	Klong Prem Prachakorn							1	1
17	Rama 6							1	1
18	Ratchasima							1	1
19	Krung Kasem	33	33	33	33	33	33	1-3	1-4.6
20	Soi Phophan Dindaeng			100	100	100	100	4	5.8
21	Nakhon Pathom							1	1
22	Yaowarat							1	1

Regarding the operational defect types of Dingdaeng District, OT was found to be the highest; the second was DE, and the lowest was DG. Ye et al. (2018) mentioned that most defect types, such as settled deposit and attached deposit, are chosen for the diagnosis of sewer pipe defects by the image recognition process in southern Chinese cities [38]. Shin et al. (2016) found that debris silty (11.0%) and obstruction (1.5%) were found in Korea's sewer pipelines [39]. Infiltration and protrusion were found to be the most significant defect types in the comparison of defect weights in Qatar and Canada [40]. Kaddoura et al. (2018) focused on the operational defects of settled deposit and infiltration by using the Multiattribute Utility Theory in decision-making, planning of budgets, and rehabilitation of sewer defects assessment. Infiltration is included under operational defects [22].

Overall, Ratchasima Road and Nakhon Pathom Road for structural condition and Soi Pracha Songkhro Road and Soi Phophan Dindaeng Road for service condition were observed to have the most sewer pipeline defects in Dindaeng District, Thailand. Moreover, Samsen Road, Vibhavadi Rangsit Road, and Krung Kasem Road also indicated large SD severity levels. This may be due to the impact of both physical factors, such as pipe diameter, depth, and slope, and the land-use of the surrounding area, including the community types and the traffic. This is the first time that such a program has been conducted in Thailand. The information about the condition of the pipelines themselves and the inspection and characterization methods should be used as a reference for maintenance programs and future assessment programs. Adjustment or development of the inspection manual should be done in collaboration with local contacts.

Conclusion

The sewer pipelines in the area under the BMA, specifically in Dindaeng District, were visually evaluated for their structural and service conditions. A robot equipped with CCTV was used to gather images and videos inside the sewer, and the information was visually analyzed in a way that complied with the New Zealand Pipe Inspection Manual. For the structural condition, surface damage was found in all 89 pipes inspected at 22 roads. Joint faulty and crack longitudinal were found in approximately 60% of the inspected sewer pipelines. For the service condition, obstruction temporary, debris silty, and debris greasy were found in 15%, 11%, and 4% of the inspected sewer pipelines, respectively. The grades of the structural condition were mainly between grade 4 and grade 5, indicating that most of the sewer pipelines in the area would need rehabilitation programs. The grades of the service condition were between excellent and good. The pipe defects could be the result of both physical factors, such as pipe diameter, depth, and slope, and the land-use of the surrounding area, including the community types and traffic.

This is the first time that a sewer assessment program has ever been conducted in Thailand. The information about the condition of the pipelines themselves and the inspection and characterization methods should be used as a reference for maintenance programs and future assessment programs. Adjustment and development of the inspection manual should be conducted in a way that promotes local participation in the process.

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