# Quantitative evaluations on the renewal and maintenance planning of sewer pipes using the normalizing degradation possibility

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#### Abstract

In Japan, the accumulation of the enormous social capital infrastructure is quickly becoming a crisis due to the low birth rate and aging population. To secure a comfortable civic life, we must advance the argument to minimize the expense of renewal and maintenance of infrastructure while maintaining the current service level. However, in small enterprises, a quantitative verification is lacking, making it difficult to plan and perform the renewal and the maintenance of the sewerage systems from a long-term viewpoint while ensuring the present service level. In this study, we quantitatively show the renewal and maintenance methods and cycle periods of pipelines considering asset management of the sewerage systems. First, we propose the deterioration probability per the standard length as a unified point of view in the sewerage pipes. Comparing the standard possibility to the deterioration probability per the sewerage pipe, we can grasp the deterioration conditions of the sewerage pipelines. In addition to these deterioration's indexes, we propose renewal and re-survey rules about the follow-up period and repair cycle for the renewal and maintenance based on the possibility of severe structural degradation. Using practical applications of the renewal rules, we quantitatively show that the cycle can be extended, decreasing the maximum repair length per year and extending the repair length in this renewal project.

## Keywords

Asset management, Renewal and maintenance planning, Sewerage systems, Normalizing degradation possibility

# 1 Introduction

Due to the massive population increase and industrialization in the late 20<sup>th</sup> century, Japan built up its infrastructure. Recently, vast amounts of the social infrastructure, such as water, sewer, electric, gas, road, and river services, are becoming too old to work, threatening daily life. Moreover, global

climate change has increased the risk of a natural disaster such as local flooding due to torrential rain, Tonankai earthquakes, and dislocation earthquakes. However, the capital for infrastructure maintenance and renewal has dramatically declined due to the recent low birth rate and aging population in Japan. Collectively the water and sewer services in Japan own 120 trillion yen worth of property (sewer business: 80 trillion yen, water business: 40 trillion yen). Thus, controlling maintenance and renewal is important. Moreover, to secure a comfortable civic life that at a minimum maintains today's standards in the future, it is important that business organizers discuss how to control the maintenance and renewal of facilities.

In a study about asset management, Miyasaka and Iwata<sup>1)</sup> suggest that it is indispensable to construct a logic model shown by a causal relationship between an objective and its means, build a new public management (NPM)-innovated contractual-type system by efficient use of private finances, and operate this management cycle efficiently. However, the business organizers of the sewer business consist almost entirely of a small-scale city or town, making it difficult to verify quantitatively how to promote the long-term renewal of sewer facilities and control of maintenance while ensuring the service level under limited financial resources. To establish both short- and long-term schemes about the renewal of facilities and maintenance in the short and long terms, it is important to practice asset management of facilities as business organizers.

Under these circumstances, a database about the sewer pipeline's degradation based on The Guidelines for Sewage Works Technical Management<sup>2)</sup> was created in September 2011<sup>3)</sup> for installation support of asset management of the sewer business by National Institute for Land and Infrastructure Management. By using this database, Matsumiya et al.<sup>4)</sup> quantitatively estimated the prediction formula of soundness and the predictive quantity of the renewal business. However, this prediction formula of soundness adopted the elapsed years only as an explanatory variable. Consequently, this model does not reflect various factors on the deterioration level such as material of the sewer pipes, internal diameter of the pipes, and laying state. Additionally, Fujio<sup>5), 6)</sup> quantitatively estimated the rate of length for each emergency level in elapsed years by applying the normal rate to a Weibull distribution. However, this study did not discuss how to exercise renewal planning of facilities with respect to costs and benefits.

In particular, Kaito et al.<sup>7)</sup> built a deterioration hazard model by the Markov process for the deterioration process of sewer pipes in hume-pipes, estimated the expected life of sewer pipes, established a unique methodology about the optimum repair and renewal planning of sewer pipes based on minimizing the expected life cycle costs upon considering various risks, and estimated the sewer pipe data in Osaka City. However, the ratio of hume-pipe in Nagaokakyo City in the Kyoto Prefecture is no more than 11.2%. Hence, the deterioration process of ceramic pipes and polyvinyl chloride (PVC) pipes has yet to be grasped quantitatively.

Using the sewer business in Nagaokakyo City as a target, our research devises a quantitative index for the deterioration level of various sewer pipes. Herein we develop a scheme to evaluate quantitatively the timing of renewing and re-surveying ceramic pipes, polyvinyl chloride (PVC) pipes, and hume-pipes in terms of minimizing the lifecycle costs and promoting asset management of sewer facilities.

The rest of this paper is organized as follows. Chapter 2 reviews the conditions and problems with the sewer business in Nagaokakyo City. Chapter 3 proposes a framework, suggests a quantitative and specific index on the deterioration level of various pipes, and constructs the deterioration process model by the Markov process. Chapter 4 proposes rules for pipe renewal and re-surveying based on performance specifications, while Chapter 5 quantitatively assesses the renewal and re-survey years of ceramic pipes in Nagaokakyo City. Finally, Chapter 6 summarizes the research results and arranges the various tasks to promote asset management of sewer facilities.

# 2 Conditions and Problems

#### 2.1 Sewer business in Nagaokakyo City

Our study targets Nagaokakyo City, which is located on flat protected lowland in the Kyoto Prefecture of Japan (Fig. 1). Nagaokakyo City covers an area of 19.18 km<sup>2</sup> and has a population of 80,597 people. The population density for inhabitable land is about 7, 000 people/km<sup>2</sup>.



# Japan Kyoto Prefecture Nagaokakyo City



Nagaokakyo City began treating sewage in 1974. The total length of the sewer pipes is 219,695 km and the diffusion rate of the sewer systems is 99.6% (April 1, 2014). Although the city's current population is comparable to that in 1974, the amount of drainage from homes and factories has drastically decreased due to a decline in economic activities and improvements in polluted water processing techniques. Consequently, the sewer system (both sewage pipes and disposal plants) is not operating near its designed capacity in the target area.

#### 2.2 The state of sewer pipes in Nagaokakyo City

Nagaokakyo City's sewer system is compromised of 43.1% ceramic pipes, 40.9% PVC pipes, and 11.2% hume-pipes. Thirty-seven years have already passed since the sewer business began in Nagaokakyo City. Soon the sewer facilities will need to be renewed as 50 years will have passed since the sewer facilities were laid. Moreover, the diffusion rate of the sewer systems is almost 100%, and citizens demand reliable sewer systems that meet or exceed the current level of service.

To quantitatively assess where, when, and how to devise a pipe renewal plan, it is important that the plan targets pipes so that the deterioration level of the pipes does not exceed the numerical criterion. That is, the infrastructure risk management must be quantitatively controlled. In the following chapter, we propose the deterioration probability for evaluating the deterioration level in sewer pipes quantitatively by constructing a deterioration process model.

# **3** Proposition of the deterioration probability and the deterioration level in sewer pipes

#### 3.1 Deterioration determination of sewer pipes

The deterioration determination of sewer pipes is mainly based on the Guidelines for Sewage Works Technical Management<sup>3)</sup> determined by the Japan Sewage Works Association. Nagaokakyo City's pipe survey adopted these Guidelines. The survey components are pipe corrosion, vertical sagging, pipe breakage, cracked pipes, pipe joint's gaps, and water infiltration. For pipes, each survey component is determined as a pipe degradation state. The pipe degradation states are as follows:

- damage condition: m=0(normal level)
- damage condition: m=1(slightly damaged level)
- damage condition: m=2(moderately damaged level or severely damaged level)

Herein in terms of safety, both moderately damaged and severely damaged level are determined as a severely damaged condition.

Each span in adjacent manholes consists of multiple pipes. The survey data consists of the damage condition of the survey components for every pipe in a span. By counting the number of pipes with a damaged condition for the survey components, the pipe degradation state as a span is determined. Table 1 shows the deterioration determination and damage condition in sewer pipes by survey component. By surveying the vertical sagging pipe joint's gap in the sewer pipes, not only the pipe degradation state but also the joint effect is adequately taken into consideration as the deterioration determination.

survey	material of sewer pipes (k=1,2,3)		damage condition (m=1,2)			
components			slightly damaged level	moderately damaged level		
(n=1,2,6)			(m=1)	or severely damaged level (m=2)		
pipe corrosion (n=1)	ceramic pipes(k=1) hume pipes(k=2) PVC pipes(k=3)		surface roughness pipe	The aggregates or reinforce-ment rods of pipe is exposed.		
vertical sagging (n=2)	ceramic pipes(k=1) PVC pipes(k=3)		The length of vertical sagging is less $\varphi/2$ .	The length of vertical sagging is over $\varphi/2$ .		
	huma	φ<700	The length of vertical sagging is less $\varphi/2$ .	The length of vertical sagging is over $\varphi/2$ .		
	nume pipes (k=2)	$700 \leq \varphi < 1,650$	The length of vertical sagging is less $\varphi/4$ .	The length of vertical sagging is over $\varphi/4$ .		
		$1,650 \leq \varphi$	The length of vertical sagging is less $\varphi/8$ .	The length of vertical sagging is over $\varphi/8$ .		
pipe breakage	ceramic pipes(k=1)		_	Axial direction's crack is existing or a part of pipe is lost.		
(n=3)	hume pipes(k=2)		The width of axial direction's	The width of axial direction's crack		
(n=3)	PVC $pipes(k=3)$		crack is less 2mm.	is over 2mm or a part of pipe is lost.		
cracked pipe (n=4)	ceramic pipes(k=1)		_	Circumferencial direction's crack is existing.		
	hume pipes(k=2) PVC pipes(k=3)		The width of circumferencial direction's crack is less 2mm	The width of circumferencial direction's crack is over 2mm or a part of pipe is lost.		
pipe joint's gaps (n=5)	ceramic pipes(k=1)		The length of pipe joint's gap is less 50mm.	The length of pipe joint's gap is over 50mm or the pipe joint is removed.		
	hume pipes(k=2)		The length of pipe joint's gap	The length of pipe joint's gap is over		
	PVC $pipes(k=3)$		is less 70mm.	70mm or the pipe joint is removed.		
water infiltration (n=6)	ceramic pipes(k=1) hume pipes(k=2) PVC pipes(k=3)		The pipe is blotted by water infiltration.	The water infiltration is flown or blown out within the pipe.		

Table 1: Deterioration determination in sewer pipes

 $\varphi$  : internal diameter of pipes(mm)

Source: Guidelines for Sewage Works Technical Management -2003-, Japan Sewage Works Association This table is partically arranged by the author

# 3.2 Proposition and definition of the deterioration probability in survey pipes

We propose and define the deterioration probability in the survey pipes per the reference span length. The deterioration state is largely affected by the different lengths of pipes, the number of joints in the span, and material of the sewer pipe, because of the length of a ceramic pipe is 1 m, the length of a hume-pipe is 2 m or 2.43 m, and the length of a PVC pipe is 4 m. Accordingly, we convert the deterioration probability into the reference span length so that the deterioration state can be quantitative evaluated regardless of the material of sewer pipe.

First, survey pipe *i* in span *s*, which has the same elapsed years *T* and material of sewer pipe *k*. Thus, the possibility  $p_{i,n,m,T}$ , which is evaluated as damage condition *m* for survey components *n* of the survey pipe can be expressed as equation (1) based on the survey results.

$$p_{i,n,m,T} = \frac{S_{s,n,m}}{NP_s} \tag{1}$$

- $p_{i,n,m,T}$ : The possibility evaluated as damage condition m for survey components n of the survey pipe (the survey pipe i in span s, which has the same elapsed years T and material of sewer pipe k because span s has surveyed all at once.)
- $S_{s,n,m}$ : The number of survey pipes evaluated as damage condition m for survey components n in span s
- $NP_s$ : The number of pipes in survey span s
- k: Material of the sewer pipes
  - (k = 1: ceramic pipes, k = 2: hume-pipes, k = 3: PVC pipes)
- *n*: Survey components(n = 1: pipe corrosion, n = 2: vertical sagging, n = 3: pipe breakage, n = 4: cracked pipe, n = 5: pipe joint's gaps, n = 6: water infiltration)
- T: Elapsed years(T = 0, 1, ...) = survey year laying year
- *m*: Damage condition(m = 0, 1, 2)

Second, to potentially compare the deterioration probability regardless of the number of pipes in the survey span, the deterioration probability in the survey pipes  $p_{i,n,m,T}$  is converted into  $P_{i,m,T}$ .  $P_{i,m,T}$  can be expressed as

$$P_{i,m,T} = 1 - \prod_{n=1}^{6} \left( 1 - \sum_{r=m}^{2} p_{i,n,r,T} \right)^{\frac{1}{NP_s}}$$
(2)

 $P_{i,m,T}$ : The deterioration probability in survey pipe *i* included in span *s*, which has the damage condition in survey component *n* is determined as the damage condition greater than damage condition m (m = 1, 2).

This deterioration probability  $PS_{i,m,T}$  can be expressed as

$$PS_{i,m,T} = 1 - \left(1 - \sum_{r=m}^{2} P_{i,r,T}\right)^{\frac{L}{L_k}}$$
(3)

 $PS_{i,m,T}$ : The deterioration probability in the reference span length determined damage condition m (m = 1, 2) in survey pipe i

 $L_k$ : Average length per survey pipe (m)

*L*<sup>\*</sup>: Reference span length (m)

Herein the reference span length is set to 41.5 m, which is the average value of a sewer span's length in Nagaokakyo City. Figure 2 shows the concept of the deterioration probability per span length, pipe length, and reference span length.



Each span has a different length, number of pipes, and pipe material.

Figure 2: Concept of the deterioration probability for the span length, pipe length, and reference span length

# 3.3 Proposition and definition of the deterioration probability in the reference pipes<sup>11)</sup>

We propose and show how to calculate the deterioration probability normalized by the reference span length in a reference pipe. The reference pipe is applied to the open database for the sewer pipeline's degradation<sup>3)</sup> of the National Institute for Land and the Infrastructure Management Ministry of Land, Infrastructure, Transport and Tourism (September, 2011) with the goal of asset management in the sewer business. Table 1 shows the survey components. The numbers of reference pipes are 25,967 spans, 511,629 pipes, and 727,086 m in total. The pipes are composed of ceramic pipes, hume-pipes, or PVC pipes. We define these pipes as the reference pipes in terms of sample sewer pipes in Japan.

The deterioration probability in the reference pipe is calculated in terms of elapsed years of survey pipes using the deterioration process model with the Markov process<sup>16)</sup>. In this deterioration process model,  $\alpha_k$  is the transition probability converted damage condition m = 0 into damage condition m = 1.  $\beta_k$  is the transition probability converted to damage condition m = 1 into damage condition m = 2 from elapsed years T to elapsed years T + 1 in the reference pipe. Figure 3 shows the concept of the damage condition by the deterioration process. The transition probability indexes  $\alpha_k$  and  $\beta_k$  are determined by the material of sewer pipe k regardless of elasped years T.

The transition probability from damage condition x to damage condition y is defined as  $w_{i,x,y}$  in reference pipe *i*, thus the transition probability index  $W_i$  can be expressed as

$$\boldsymbol{W}_{i} = \begin{pmatrix} w_{i,0,0} & w_{i,1,0} & w_{i,2,0} \\ w_{i,0,1} & w_{i,1,1} & w_{i,2,1} \\ w_{i,0,2} & w_{i,1,2} & w_{i,2,2} \end{pmatrix} = \begin{pmatrix} 1 - \alpha_{k} & 0 & 0 \\ \alpha_{k} & 1 - \beta_{k} & 0 \\ 0 & \beta_{k} & 1 \end{pmatrix}$$
(4)



(normal level) (slightly level) (moderately level or severely level)

### Figure 3: Concept of the deterioration process model using the Markov process

The vector of damage condition  $\overline{P}_{i,T}$  in reference pipe *i* can be expressed as

$$\overline{\boldsymbol{P}}_{i,T} = \begin{pmatrix} P_{i,0,T} \\ \overline{P}_{i,1,T} \\ \overline{P}_{i,2,T} \end{pmatrix} \qquad \overline{\boldsymbol{P}}_{i,0} = \begin{pmatrix} P_{i,0,0} \\ \overline{P}_{i,1,0} \\ \overline{P}_{i,2,0} \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$$
(5)

$$\overline{P}_{i,T+1} = W_i \overline{P}_{i,T} (T = 0, 1, ...)$$
(6)

 $\overline{P}_{i,m,T}$ : The deterioration probability determined as damage condition *m* in reference pipe *i* in condition of elasped years *T* 

Herein transition probabilities  $\alpha_k$  and  $\beta_k$  are estimated by maximizing the correlation coefficient R2 between the value of the deterioration probability in the survey pipe calculated by equation (2) and a value of the deterioration probability calculated by equation (6) while minimizing the total error of the estimate. Table 2 shows the results of the estimated values of the transition probability  $\alpha_k$  and  $\beta_k^{16}$ . Because all coefficients of determination about  $\alpha_k$  and  $\beta_k$  are superior to 0.6, this model is capable of extraordinary precision.

Table 2: Estimated values of transition probability  $\alpha_k$ ,  $\beta_k$  and the correlation coefficient R2

ceramic pipes	hume pipes	PVC pipes
(k=1)	(k=2)	(k=3)
a1=0.000350	a2=0.00090	<i>α</i> 3=0.00129
R2=0.745	R2=0.621	R2=0.997
β1=0.0264	β2=0.0119	$\beta 3 = 0.0277$
R2=0.871	R2=0.750	R2=0.751

The deterioration probability in the reference span length  $\overline{PS}_{i,m,T}$  determined as damage condition m(m = 1, 2) in survey pipe *i* can be expressed as

$$\overline{PS}_{i,m,T} = 1 - \left(1 - \sum_{r=m}^{2} \overline{P}_{i,r,T}\right)^{\frac{L}{L_k}}$$

$$\tag{7}$$

#### 3.4 Definition of the deterioration level in survey pipes

Deterioration level  $\delta_i$  in the survey pipe is defined as equation (8). This index can be expressed as the ratio of the damage condition using the deterioration probability of the survey pipe to the reference pipe.

$$\delta_i = \frac{PS_{i,2,T}}{\overline{PS}_{i,2,T}} \tag{8}$$

Herein, when  $\delta_i > 1$ , the survey pipe is more deteriorated than the reference pipe. Figure 4 shows the calculation flow of deterioration level  $\delta_i$  in the survey pipe.



Figure 4: Calculation flow of deterioration level  $\delta_i$  in a survey pipe

# 4 Proposition of the renewal and re-survey rules in survey sewer pipes

The maintenance period of a sewer pipe is 50 years according to the Ministerial Ordinance concerning the Useful Life of Depreciable Assets<sup>18)</sup>. However, the deterioration level of pipes varies by laying state. In reality, some pipes are completely functional 50 years after being laid, while others must be repaired or replaced before then. Due to strict monetary and labor resources, it is difficult to renew all pipes every 50 years without evaluating the deterioration state. Hence, it is essential that sewer pipes maintain normal function by controlling the methods used to determine a long-term plan for renewing, repairing, and re-surveying.

We propose a quantitative deterioration probability of sewer pipes using a quantitative and united index considering the material of the sewer pipe and the span length. Additionally, we think it useful to judge the pipe degradation state using the deterioration probability to assure normal function.

However, a pipe survey is essential to estimate the deterioration probability of sewer pipes. Moreover, based on the deterioration probability and the state estimated by the survey of sewer pipes, we must set rules for how and when to renew, repair, or re-survey with numerical criterion. Thus, we propose the renewal and re-survey rules below.

The numerical criterion of the deterioration probability of pipes (*NCPS*) is set to 0.30 in this study because the deterioration probability of the survey pipes to the reference pipes is 0.30 since 54 years have passed after laying the ceramic pipes compared with the 50 years based on the Ministerial Ordinance concerning the Useful Life, etc. of Depreciable Assets.

First, the deterioration probability  $PS_{i,2,TS_i}$  to the reference span length in survey pipe *i* and survey year  $T = TS_i$  is calculated by equation (3). Additionally, the survey year *T* is defined  $TD_i$ when the deterioration probability  $\overline{PS}_{i,2,TS_i}$  is equal to the numerical criterion in the deterioration probability of pipes (*NCPS*=0.30). The value of  $TD_i$  is 54 years for ceramic pipes. We determined the renewal year or re-survey year as follows. The pipe's states are classified as Status [1]–[5] by the value of  $PS_{i,2,TS_i}$  based on the renewal and re-survey rules.

- Status [1]: If the value of  $PS_{i,2,TS_i}$  is 0.00, the deterioration state of the pipe is assumed to advance like the reference pipe after survey year  $TS_i$ . Then the time when the deterioration probability  $PS_{i,2,TS_i}$  is equal to *NCPS* is estimated as  $TS_i + TD_i$ . Consequently, the pipe needs be re-surveyed in the future (Judgement: Re-survey) in re-survey year T [1], which is defined as  $TS_i + TD_i - 10$ . Herein 10 years represent the time for survey planning.
- Status [2]: If the value of  $PS_{i,2,TS_i}$  is smaller than *NCPS* and  $\delta_i$  is less than 1, the deterioration state of the pipe is assumed to advance like the survey pipe. Then the time when the deterioration probability  $PS_{i,2,TS_i}$  is equal to *NCPS* is estimated as  $TD_i/\delta_i$ . If the value of  $TD_i/\delta_i$  is greater than  $TS_i + TD_i$ , the pipe needs be re-surveyed (Judgement: Re-survey), and re-survey year T [2] is defined as  $TS_i + TD_i 10$ .
- Status [3]: If the value of  $PS_{i,2,TS_i}$  is smaller than *NCPS* and  $\delta_i$  is smaller than 1, the pipe is assumed renewed or re-surveyed. If the value of  $TD_i/\delta_i$  is smaller than  $TS_i + TD_i$ , the pipe needs be renewed (Judgement: Renewal), where renewal year T [3] is defined as  $TD_i/\delta_i$ .
- Status [4]: If the value of  $PS_{i,2,TS_i}$  is smaller than *NCPS* and  $\delta_i$  is greater than 1, the deterioration state of the pipe is worse than that of the reference pipe. The pipe needs be renewed (Judgement: Renewal), and renewal year T [4] is defined as  $TD_i/\delta_i$ .
- Status [5]: If the value of  $PS_{i,2,TS_i}$  is larger than *NCPS*, the pipe must be renewed soon (Judgement: Urgent renewal), where renewal year T [5] defines survey year  $TS_i$ .

Table 3 summarizes the renewal and re-survey rules.

Status	Criterion						
	$PS_{i,2,TS_i}$	$\delta_i$	$TD_i/\delta_i > TS_i + TD_i$	Judgement	Renewal year	Re-survey year	
[1]	0.00	0		Re-survey		$T[1] = TS_i + TD_i - 10$	
[2]	< NCPS	< 1	Yes	Re-survey		$T[2] = TS_i + TD_i - 10$	
[3]	< NCPS	< 1	No	Renewal	$T[3] = TD_i/\delta_i$		
[4]	< NCPS	≧1	No	Renewal	$T[4] = TD_i/\delta_i$		
[5]	$\geq NCPS$	≧1	No	Urgent renewal	$T[5] = TS_i$		

Table 3: Summary of the renewal and re-survey rules

Figure 5, which plots elapsed years T as the horizontal axis and the deterioration probability in the reference span length as the vertical axis, shows the plots of the survey year, the renewal year, and the re-survey year based on the renewal and re-survey rules (Table 3). Herein the renewal year (T [3], T [4], and T [5]) and the re-survey year (T [1] and T [2]) are estimated by the deterioration probability of the reference span length in the survey year. Also, by applying the re-survey results for the renewal and re-survey rules to the deterioration probability of reference span length in the re-survey year (T [1] and T [2]), the new renewal year or next-survey year can be determined. Moreover, Fig. 6 shows the relation between the renewal year, the re-survey year, and the deterioration probability in the survey year based on the renewal and re-survey rules.



Figure 5: Renewal and re-survey rules using the deterioration probability



Figure 6: Renewal and re-survey years by the deterioration probability of the survey year

# 5 Evaluation on the renewal and re-survey business in sewer pipes

### 5.1 Overview of the sewer pipe survey conducted in Nagaokakyo City

In Nagaokakyo City, based on the Guidelines for Sewage Works Technical Management<sup>3</sup>, the TV camera survey of the sewer pipe was carried out in 2011-2013. Table 4 overviews the TV camera survey. The survey evaluated 4.92% of the ceramic pipes and 0.47% of the PVC pipes. It should be noted that the survey was unable to evaluate the hume-pipes because the aim of this survey was mainly for pipes with water leaks. Figure 7 shows the length for each laying year and materials of the sewer pipes. The rate of pipe laying before 1995 was about 40%, and of this, about 89% were ceramic pipes.



Length(m)

Figure 7: Length in each laying year and material of sewer pipes

	The sewer pipes conducted by TV camera survey				Total	Ratio
material of sewer pipes	Surveying	Number	Number	Length	Length	(%)
	year	of spans	of pipes	( <i>m</i> )	( <i>m</i> )	
ceramic pipes(k=1)	under 31	177	4,355	4,333	88,028	4.92%
hume pipes(k=2)	-	0	0	0	24,275	0.00%
PVC $pipes(k=3)$	under 31	24	140	394	83,424	0.47%
Total	-	201	4,495	4,727	195,727	2.42%

Table 4: Overview of the TV camera survey in Nagaokakyo City

We evaluated only ceramic pipes in Nagaokakyo City as a target because this material is the most prevalent. Based on the sample data, the ratios of renewal and re-survey years in ceramic pipes were calculated by the renewal and re-survey rules. The ceramic pipes in Nagaokakyo City were laid from 1978 to 1998. They were surveyed 15 to 31 years after the pipes were laid.

### 5.2 Rates of renewal and re-survey years in ceramic pipes in Nagaokakyo City

Using the TV survey's results in Nagaokakyo City, we estimated the rate of renewal and re-survey years for ceramic pipes by the renewal and re-survey rules. Figure 8 shows the rate of renewal and re-survey for ceramic pipes by elapsed years.



Figure 8: Rate of renewal and re-survey in ceramic pipes by elapsed years

According to the results, 74.6% of the pipes should be re-surveyed (status [1] [2]), and the average elapsed time is 65.7 years (from 59 years to 75 years after laying pipe). The rate of renewal (status [3] [4]) is 24.3%, and the average elapsed time is 53.0 years (from 17 years to 80 years after laying pipe). The rate of urgent renewal (status [5]) is 1.1%, and the average elapsed time is 19.4 years

(from 16 years to 29 years after laying pipe). Hence, a renewal plan for the pipes based on a quantitative evaluation is urgently needed.

### 5.3 Evaluation of renewal and re-survey years in ceramic pipes in Nagaokakyo City

Based on rate of renewal and re-survey in ceramic pipes by elapsed years, Fig. 9 shows the renewal and re-survey length by year considering the laying year and the length about ceramic pipes in Nagaokakyo City.

In the case of constant renewal at 54 years after laying that the deterioration probability in the reference span length with a damage level m = 2 for the ceramic reference pipes is 30%, the renewal period is 21 years (from 2032 to 2052), and the total renewal length is 88,028 m. Hence, the maximum renewal length of 8,284 m will be in 2048. For Status 1) – 4), we estimated the renewal and re-survey length based on the renewal and re-survey rules.

- The urgent renewal length (status [5]) is 944 m, which is a renewal rate of 1.07% for the total laying length 88,028 m. Additionally, the period for urgent renewal is spread over 34 years (from 1994 to 2027), and the maximum of renewal length in a year is 59 m for 2010.
- 2) Of the 88,028 m of ceramic pipes, the renewal length (status [3] or [4]) is 21,456 m, which is 24.37%. The renewal process can be spread over 84 years (from 1995 to 2078), where the maximum of renewal length of 633 m will occur in 2048.
- Of the 88,028 m of ceramic pipes, 65,628 m, or 74.56%, needs be re-surveyed (status [1] or [2]) over 37 years (from 2037 to 2073). The maximum re-survey length of 3,690 m will be in 2054. By applying the re-survey results for the renewal and re-survey rules, the new renewal year or next-survey year will be determined.
- 4) In 2016, 2,483 m, or 2.82% of the total pipe length, requires urgent renewal.



Figure 9: Renewal and re-survey length by year

#### 5.4 Investigation

When business organizers perform renewal or re-survey actions based on the renewal and re-survey rules, the average renewal year for a ceramic pipe exceeds 50 years, which is longer than the estimated renewal period of 50 years by the notification of the Ministry of Land, Infrastructure, Transport and Tourism<sup>17)</sup>. In addition, the deterioration probability of the survey pipe to the reference pipe is 0.30 since 54 years have passed after laying the ceramic pipes. This result indicates that it is possible for survey pipes to have a long useful life in terms of pipe's deterioration state by applying our renewal and re-survey rules.

Compared to the constant renewal case, the maximum renewal is reduced at its peak from 8,246 m to 3,690 m. In addition, the renewal can be prolonged from 21 years (2032–2052) to 84 years (1995–2078). Hence, the renewal business can be spread out over an extended period, allowing for more efficient utilization of resources.

Moreover, the re-survey length is 65,628 m over 37 years (2037–2073), and the maximum re-survey length in a given year is 3,690 m in 2054. By applying the re-survey results for the renewal and re-survey rules, the new renewal year or next-survey year can be determined. Even if all the re-survey results indicate renewal is urgently needed, the renewal period would span 85 years. The maximum renewal length would be 4,006 m in 2054. Consequently, the renewal business can be leveled out over a longer period. If the re-survey results do not project urgent renewal, the timing of renewal or the next-survey can be further prolonged, allowing the renewal business to span over an even longer period. For the efficient sewer renewal business, we must first create a proper survey and re-survey schedule of sewer pipes, then devise a renewal plan and promote the renewal business.

Based on information from various sources such as the laying state, past records of broken or leaking water pipes, and inhabitant's reports of unusual sewer pipes, 2,483 m of ceramic pipe must be renewed in 2016. Business organizers should renew or repair these specific pipes immediately.

#### **6** Conclusion

This study examines the conditions and problems with Japan's infrastructure, mainly the sewer pipe systems. We suggest a quantitative and specific index for the deterioration level of various pipes and propose rules for pipe's renewal and re-surveys based on performance specifications. As a case study about ceramic pipes in Nagaokakyo City, we quantitatively assessed the renewal and re-survey years based on the renewal and re-survey rules. Applying the proposed renewal and re-survey rules, the maximum renewal length by year can be reduced and the renewal business can be extended compared to the constant renewal case. Thus, we quantify the leveling of replacement rates and reduction in the peak replacement. Moreover, if the status of the re-survey results does not estimate urgent renewal, the timing of renewal or next-survey can be further extended, indicating

even more efficient use of resources. Thus, we suggest that business organizers create a survey, re-survey, and renewal schedule of sewer pipes that grasps the pipe degradation state properly.

In the next stage of this study, we aim to estimate a survey, re-survey, and renewal schedule to minimize the total life-cycle costs, including survey costs and renewal costs, for all types of pipes (ceramic, PVC, and hume-pipes) in Nagaokakyo City. Moreover, we plan to set the numerical criterion and the determination of priorities in the survey and renewal pipes so that sewer business organizers can practically construct a renewal system and control maintenance.

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