Method for Estimating Inner Surface Corrosion of Telecommunication Pipes Based on Inspection Data

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ABSTRACT: To maintenance underground facilities which buried over a wide area efficiently, it is needed to predict corrosion of the facilities with extensively maintained data such as elevation. Using the past inspection data, we developed a method to predict areas which has severe corrosion rate and prediction expression for years buried and corrosion rate in the areas. This technique enables us to predict the corrosion of the inner surface of the pipeline without additional inspection.

1. 1. BACKGROUND

The maintenance and management of constructed civil engineering facilities is an important issue for each country. Here, degradation is an element that cannot be ignored especially in the case of facilities for which a long time has elapsed since their construction. It must be dealt with by performing inspections and repair/reinforcing work as needed. However, in the case of underground facilities, it is difficult to perform inspections frequently, so it is important to predict degradation so that repair/reinforcing work can be performed efficiently. In this article, our aim is to predict degradation in existing underground facilities from past inspection results, and to this end, we take up underground telecommunication pipes in Japan as the target of our study.

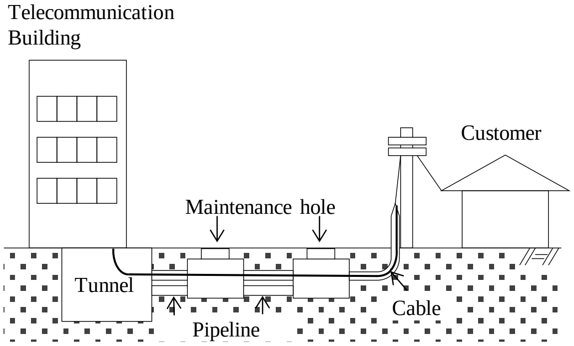


Figure 1 Telecommunication facilities in Japan

In Japan, cables are laid out between telecommunication buildings and between those buildings and customers to enable communications. These cables are installed inside of pipes to protect against external forces due to other types of engineering work or disasters such as earthquakes. Basically speaking, only one cable is installed in one pipe, so there are now many pipes in Japan having a total length of approximately 620,000 km. In addition, a manhole exists approximately every 150 m for the purpose of cable laying and cable maintenance and management, and pipes are laid in a manhole-to-manhole manner. An overview of telecommunication facilities in Japan is shown in Figure 1. Most pipelines were constructed from the 1960s to 1970s, so there are many pipes for which 50 to 60 years have passed since their construction as Sugino and Masakura (2014) mentioned. These pipes, and old ones in particular, are metal pipes made of carbon steel or cast iron, and over the long term, the effects of corrosion cannot be ignored. A histogram of year of pipe installation versus material quality is shown in Fig. 2. As shown in Fig. 3, the inner surface of a carbon steel pipe is coated while its outer surface is wrapped in asphalt-baked jute or coated with polyethylene. Since pipes are buried in the ground under roads, outer-surface inspections conducted for this study make use of data obtained by inner-surface inspections that are performed relatively frequently. Inner-surface inspections of pipes centered about pipe cameras can be performed when laying cables, for example. If rust is found on the inner surface using a pipe camera, the inspection judges the cable to be corroded. An example of rust on a pipe's inner surface and an example of a sound pipe are shown in Fig. 4. There are many cases of fresh water penetrating the inner surface of underground telecommunication pipes, which can cause corrosion to occur. Past surveys of water quality on the inner surface of pipes revealed fresh water investigated as far as investigated by Ito et al (2018). The speed of corrosion by fresh water can be estimated using, for example, the formula devised by Ozawa and Akashi (2017). However, the large number of existing pipes makes surveying the inner-surface water quality of all pipes unrealistic. Against this background, our objective in this article is to statistically develop a technique that can classify the range of severe corrosion on a pipe's inner surface and the locations where corrosion is difficult to occur using as indices external factors that can affect inner-surface water quality and a technique for making future predictions.

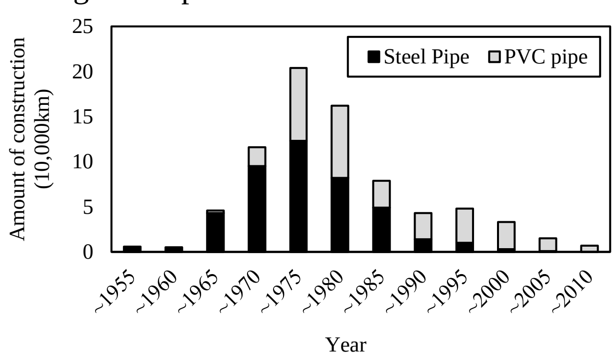


Figure 2 Histogram of year of pipe installation versus material quality

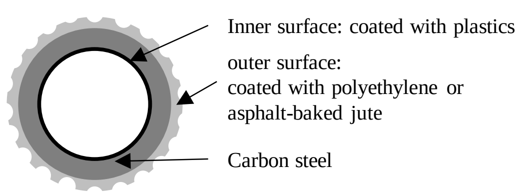
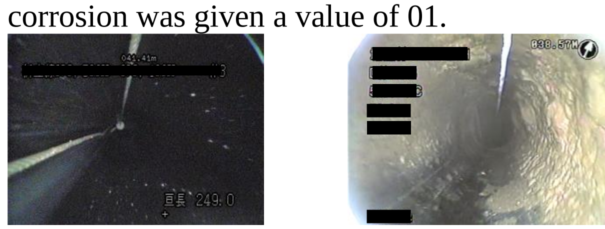


Figure 3 Constitution of steel pipe

2. MATERIAL AND METHOD

The peripheral environment of an underground pipe is thought to affect the moisture on the pipe's inner surface. Since most pipes lie under paved roads, the road periphery is usually backfilled with mountain sand. However, it is thought that the peripheral environment can affect the quality of water penetrating a pipe's inner surface and the water level. For this reason, we assigned a peripheral environment to each pipe using publically available data in Japan and began our study by searching for peripheral-environment information that is significantly related to corrosion. In the end, we selected the parameters listed in Table 1 from Ministry of Land, Infrastructure and Transport (2023). These are indices that seems to be related to corrosion in Japan in addition to the number of years buried. We constructed a database by assigning those parameters to each pipe interconnecting two manholes. In the results of inspecting the inner surface of pipes by a pipe camera to obtain corrosion data, the case of confirming the existence of corrosion or of repairing a pipe with corrosion was given a value of 01.



(a) Sound inner surface (b) Rust on inner surface

Figure 4 Samples of inner surface

Table 1 Peripheral-environment data used in study

Item Name	*Description*
Precipitation	*Numerical value*
Average air temperature	*Numerical value*
Elevation	*Numerical value*
River basin	*Categorical variable*
Topography	*Categorical variable*
Soil	*Categorical variable*
Surface	*Categorical variable*
Water area	*Boolean value*
Lowlands	*Boolean value*

We then subjected the selected parameters and corrosion data to statistical testing to determine whether any significant relationships could be obtained. Specifically, we applied a t-test to numerical data to evaluate whether a significant difference exists in the difference between average values, applied a chi-squared test ($\chi 2$ test) to Boolean data, and created a cross-tabulation table to evaluate categorical variables using Cramer's coefficient of association. The significance level for the t-test and $\chi 2$ test was set to 5%.

We used the results from six areas in Japan (Iwate, Saitama, Westside of Western Chiba, Kouchi, Fukuoka, and Kumamoto) as pipe inspection data. Approximate positions are shown in Fig. 5 and the number of corroded pipes, the rate of corrosion, and average age of facilities in years for each area are listed in Table 2. The area with the highest rate of corrosion was found to be Iwate and that with the lowest was Fukuoka. The average age of all pipes was 36.8 years and the average age in each area was between 30 and 40 years.

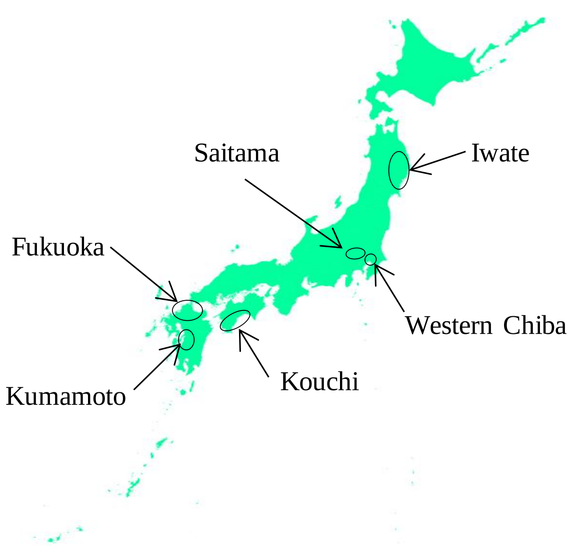


Figure 5 Location of inspection data

Table 2 Data detail by area

	Data items (corroded)	*Corrosion rate*	*Average age in years*
All	*16102 (1520)*	*0.094*	*36.8*
Iwate	*1722 (276)*	*0.160*	*37.7*
Saitama	*2137 (214)*	*0.100*	*33.4*
Western Chiba	*1622 (123)*	*0.076*	*37.4*
Kouchi	*1813 (123)*	*0.067*	*39.4*
Fukuoka	*4310 (166)*	*0.039*	*35.8*
Kumamoto	*4498 (618)*	*0.137*	*33.8*

3. RESULTS AND DISCUSSION

3.1. Significance testing of variables

Results of investigating numerical data consisting of annual precipitation, annual average air temperature, and average elevation are listed in Tables 3 to 5. For annual precipitation, no significance was found in two areas. Additionally, even in areas where significance was found, the results for Iwate, Western Chiba, and Fukuoka showed much precipitation for the case of corrosion, but for Kumamoto, they showed much precipitation for no corrosion. Furthermore, in Iwate and Kumamoto where the corrosion rate is high, the amount of precipitation is greatly different between these two areas, so there is a high possibility that classifying corrosion trends using precipitation is difficult. Although precipitation is thought to affect the amount of moisture inside a pipe, the results of surveys have shown that no manholes exist in which no moisture has been observed, and while a state in which moisture always exists inside a pipe given a certain amount of precipitation can be considered, a macro viewpoint would suggest that the amount of precipitation cannot easily affect pipe corrosion.

Next, in the case of annual average air temperature, a significant difference could be seen in all areas other than Fukuoka. Nevertheless, there is no fixed relationship between average air temperature and corrosion in these areas. For Iwate, Western Chiba, and Kumamoto, the corrosion rate for the case of high temperatures tends to be high, but for other areas, the opposite trend can be seen. In addition, Iwate and Kumamoto, which have high corrosion rates, differ greatly in air temperature, so it is difficult to effectively use average air temperature in predicting corrosion. In general, corrosion proceeds rapidly as a chemical reaction under high temperatures. This time, we evaluated on the basis of air temperature, but there was no temperature difference that could speed up such a reaction, and the possibility exists that underground temperatures are more stable than outside air temperatures. Since temperature differences do not easily occur in each of these areas, it is thought that no significant differences existed as was the case in this study. Similarly for average elevation, there was no fixed trend despite areas with a significant difference, so investigating corrosion trends using elevation is likewise difficult. Although water can be expected to collect easily at low-altitude locations, here as well it is thought that elevation has no effect on moisture inside a pipe.

Table 3 Annual precipitation

	No corrosion, average values (mm)	*Corrosion, average values (mm)*	*t-test results*
Iwate	*1450.5*	*1538.2*	*Significant*
Saitama	*1292.7*	*1284.7*	*Not significant*
Western Chiba	*1363.4*	*1371.8*	*Significant*
Kouchi	*2470.1*	*2501.3*	*Not significant*
Fukuoka	*1750.0*	*1766.3*	*Significant*
Kumamoto	*2050.2*	*2025.7*	*Significant*

Test results for data having Boolean values are shown in Tables 6 and 7. First, as for the existence of a water area, there are regional areas with no significance, and in addition, the existence or non-existence of a water area has no effect on corrosion rate. Next, as for whether the pipe lies in lowlands, results revealed that no area shows a significant difference in terms of the presence of corrosion. Precipitation, elevation, water area, and lowlands each have values that can be thought to affect the amount of water moisture inside the pipe, but considering that surveys to date have shown that water generally exists inside manholes, it can be thought that the

Table 4 Annual average temperature

	No corrosion, average values (°C)	*Corrosion, average values (°C)*	*t-test results*
Iwate	*10.53*	*10.97*	*Significant*
Saitama	*14.98*	*14.90*	*Significant*
Western Chiba	*14.99*	*15.29*	*Significant*
Kouchi	*16.18*	*15.59*	*Significant*
Fukuoka	*16.17*	*16.16*	*Not significant*
Kumamoto	*16.27*	*16.60*	*Significant*

Table 5 Average elevation

	No corrosion, average values (m)	*Corrosion, average values (m)*	*t-test results*
Iwate	*74.21*	*45.42*	*Significant*
Saitama	*23.1*	*26.0*	*Not significant*
Western Chiba	*13.9*	*9.7*	*Significant*
Kouchi	*74.0*	*124.4*	*Significant*
Fukuoka	*21.44*	*21.44*	*Not significant*
Kumamoto	*67.50*	*38.04*	*Significant*

Table 6 Results of χ^2 test on water area

Area	Water area present, corrosion rate	No water area, corrosion rate	Results of χ^2 test
Iwate	0.134	0.170	Not significant
Saitama	0.100	0.099	Not significant
Western Chiba	0.102	0.064	Significant
Kouchi	0.075	0.041	Significant
Fukuoka	0.037	0.041	Not significant
Kumamoto	0.133	0.192	Significant

Table 7 Results of χ^2 test on lowlands

Area	Lowlands, corrosion rate	Not lowlands, corrosion rate	Results of ^{2} test
Iwate	0.126	0.162	Not significant
Saitama	0.147	0.099	Not significant
Western Chiba	0.065	0.077	Not significant
Kouchi	0.075	0.067	Not significant
Fukuoka	0.039	0.039	Not significant
Kumamoto	0.168	0.136	Not significant

above four conditions basically do not affect whether water enters the interior of a manhole in Japan.

Next, the results of evaluating Cramer's coefficient of association for categorical variables are shown in Table 8. Here, a relationship with corrosion could be judged to exist if the Cramer's coefficient of association exceeded 0.1, and it was only the classification by river basin that satisfied this requirement for all regional areas. These results, which can be divided into which river basins the pipes in each area belong to, show that corrosion concentrates in units of river basins in each area. For example, the results listed in Table 9 divided into units of river basins in Western Chiba show high corrosion rates for three rivers and low corrosion rates for three other. Here, any river in this area that did not satisfy the collection of 50 data items was excluded. The corrosion rate for all of Western Chiba was 0.076, so it can be seen that the corrosion rate when divided into units of river basins varied from the average. In this way, dividing results into units of river basins reveals the possibility of obtaining locations with severe corrosion and those with light corrosion. A river basin indicates the range within which water from a rainfall flows into that river. It can therefore be thought that water will flow through locations having similar soil and surface geology,

Table 8 Cramer's coefficient of association for each categorical variable

Area	River basin	Topography	Soil	Surface
Iwate	0.364	0.094	0.135	0.124
Saitama	0.377	0.139	0.167	0.132
Western Chiba	0.285	0.087	0.230	—
Kouchi	0.487	0.091	0.157	0.207
Fukuoka	0.236	0.032	0.054	0.083
Kumamoto	0.643	0.146	0.136	0.078

Table 9 Corrosion rates in units of river basins in Western Chiba (top three rivers and bottom three rivers)

River name	Corrosion rate
Ohori river	0.276 (27/98)
Old Edo river	0.157 (13/83)
Sakai river	0.139 (15/108)
Otsu river	0 (0/81)
Tsukushino river	0 (0/57)
Shinsaka river	0.033 (2/60)

which suggests the possibility that water quality inside underground pipes within the same river basin will likewise be similar. In short, judging corrosion trends in units of river basins may be treated as a reasonable approach to a certain extent.

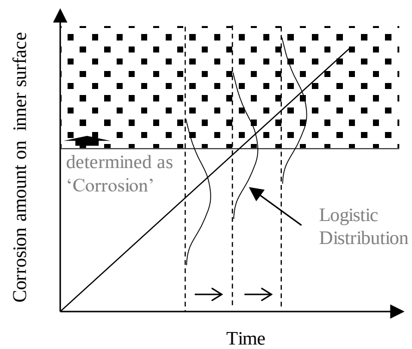
As a result of performing tests on each variable in each area as described above, we have uncovered the possibility that the most effective approach is to divide results into units of river basins and calculate corrosion rates from past inspection results to predict locations with severe corrosion.

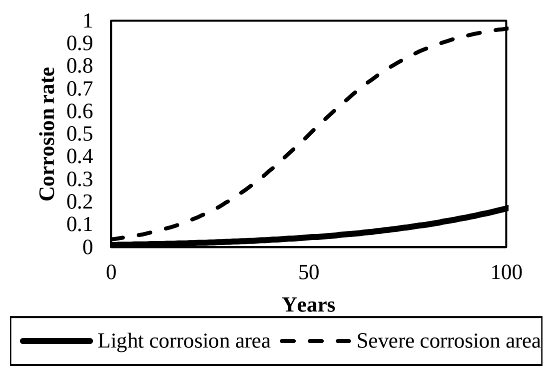
3.2. Change in Corrosion Rate Over Time in Units of River Basins

We have found that determining corrosion trends for each variable, dividing results into units of river basins, and dividing those results into locations with severe corrosion and those with light corrosion is possible. In the following, we consider a prediction formula for showing how corrosion rate changes over time in both locations with severe corrosion and locations with light corrosion. To begin with, we distinguish between locations with severe corrosion and those with light corrosion by tabulating past inspection results and creating a histogram. This time, we target only cases having 50 or more items of inspection data within the same river basin and create a histogram by defining locations with a corrosion rate greater than 0.15 as having severe corrosion and those with a corrosion rate less than 0.05 as having light corrosion. The river basins targeted in each area are listed in Table 10 and respective histograms are shown in Fig. 6. We now plot the corrosion rate for each period and consider a corrosion prediction formula. For this formula, we use a sigmoid curve, which is a cumulative distribution function of a logistic distribution. This assumes that the speed of corrosion is linear as outlined in Fig. 7 and that variation in initial state, etc. at a certain time is given by a logistic distribution. In other words, we use Eq. (1) as a model.

$$\frac{1}{2}\left(\tanh\left(\frac{x-\mu}{2s}\right)+1\right) \qquad (1)$$

For this model, we inferred a model formula using the least squares method with μ and s as variables. Approximation results are shown in Fig. 8. Here, u is 50.3 and s is 0.033 in the estimation formula for locations with severe corrosion and u is 151.9 and s is 0.015 in the estimation formula for locations with light corrosion. As a result, it is estimated that a difference of 101 years occurs between locations with severe corrosion and locations with light corrosion before reaching a corrosion rate of 0.5.





4. CONCLUSION

In this paper, we statistically analyzed the elements that affect corrosion targeting corrosion on the inner surface of telecommunication pipes in Japan. Then, based on the results of that analysis, we proposed a formula for predicting the corrosion rate within ranges corresponding to the severity of corrosion.

(1) On statistically analyzing peripheral-environment data such as weather and topography considering that they may affect corrosion on the inner surface of pipes, we found that the only effective approach is to divide

inspection results into units of river basins in each regional area.

(2) We defined river basins with severe corrosion and river basins with light corrosion in terms of corrosion rate and established a prediction formula using the cumulative distribution function of a logistic distribution as a model. A difference of 101 years could be observed between the two types of locations before reaching the same corrosion rate of 0.5.

Going forward, the validity of dividing inspection results into units of river basins must first be confirmed by measuring the quality of underground water. While it can be thought that water quality will likely be similar in units of river basins, that possibility must be clarified through on-site surveys. There is also room for modifying the model formula. In this study, the speed of corrosion was taken to be linear and we expressed that dispersion as a logistic distribution. However, we must analyze corrosion speed based on knowledge from electrochemistry and other fields and search for a more appropriate model.

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