Assessment of galvanized steel pipes for water service in buildings by direct diagnosis method

Cheol-Ho Bae, No-Suk Park, Sang-Young Park, Hyun-Dong Lee and Seong-Ho Hong

ABSTRACT

Water service pipes made of galvanized steel were assessed by direct diagnosis according to major water basins, age of pipe, and their diameters. The tubercle growth and the hydraulic cross sectional area reduction rates from examination with the visual assessment showed that there was little difference among main water basins. However, comparing the results showed that their rates depended on the age of pipe indicating that as ages increase, their rates tend to decrease. Also, in the case of over 40 mm diameter, those rates tend to be higher than the case of less than 40 mm diameter. From the results of physical properties analysis, even though most of the sampled pipes satisfied Korea Standards (KS) of tensile strength and chemical composition, 90% of the sampled galvanized steel pipes could not satisfy KS of elongation. It could be thought that elongation was seriously effected by pipe deterioration in the view of physical properties and chemical compositions. In addition, the results of scale composition analysis revealed that the component ratio of Fe was highest, whose percentage was from 54.3 ~ 69.8%, and then that of Zn was 0.09 ~ 6.34%. In comparing corrosion rates on three water basins, the maximum corrosion rates of Nakdong-River basin was 0.064 mm/year (mmpy), higher than those of other basins. Also, the diameters of the sampled galvanized steel pipes increased the corrosion rates.

Key words | corrosion rate, direct diagnosis, galvanized steel pipe, visual assessment

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INTRODUCTION

Recently, red-water and quality deterioration from the tap have increased citizen's complaints. These are directly related to aesthetical problems. Especially, mass media dealing with pathogenic microbiology and quality deterioration in tap-water have provoked the hatred of the people in Korea. Even though the government have invested a lot of capital in water quality management, such as the introduction of advanced treatment process (e.g. ozone and activated carbon), rehabilitation of aged water mains, and made every effort to improve the water quality from the tap, actually these are ineffectual. Since most cases of red-water and quality deterioration from the tap happen in storage tanks and service pipes in buildings, it is difficult to diagnose and manage them without disjoint (Lee *et al.* 2002*a*, 2002*b*, 2002*c*, 2002*d*).

From the viewpoint of drinking water supply, service pipes in buildings are located at the end of the supplying system. Even though raw water is adequate and the produced water from water treatment plants (WTPs) is safe and acceptable, without managing service pipes in buildings, the protection of public health could not be guaranteed from the water supply. In Korea, it is urgent to manage service pipes in buildings including rehabilitation of aged service pipes and the establishment of a maintenance methodology. Since, being different from water supply mains, service pipes in buildings should be managed by each end user or building manager in Korea,

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inside sweep or rehabilitation is hardly carried out in their lifetime. Also, the rehabilitation work of service pipes in building calls for a great deal of labor. Accordingly for effective and economical rehabilitation, first of all, the establishment of evaluation criteria and diagnosis methodology of aged service pipes is immediately required.

Regardless of the importance of service pipes in buildings, little research on those have been conducted until now. Several researchers have made efforts only to improve the malfunction of water mains. Especially, they have focused the development of the alternative to rehabilitation and the determination of the proper time of that, based on the analysis of the causes and characteristics of the deterioration of water mains (Chung *et al.* 2001).

Also, separating from water mains, most of the services pipes in buildings are installed in concrete walls or the soil, or exposed to the air. That is, the laying conditions of each pipe is extremely different from each other.

Recognizing the significance of services pipes in buildings and the need to more closely look at it, in this study, water service pipes made of galvanized steel were assessed by the direct diagnosis according to major water basins, age of pipe, and diameter.

MATERIAL AND METHODS

Aged service pipes

In order to evaluate the deterioration of water service pipes, 87 water service pipes made of galvanized steel were sampled from several apartments in Korea. Tables 1 and 2 summarize the characteristics and distribution of the sampled pipes according to age of pipe and diameter.

Evaluation method

Generally, evaluation methods of water supply pipes are categorized into direct and indirect diagnosis. Indirect diagnosis is carried out based on information of pipe failures or accidents, and laying conditions, on the other hand; direct diagnosis is done by sampling a fragment from the laid pipe, conducting the property test, and measuring the thickness. In direct diagnosis, although it takes a lot of time for excavation work and sampling, highly reliable and accurate information can be acquired.

Table 1 | The distribution of sampled galvanized steel pipes (GSPs) according to age of pipe

Age of pipe (years)	10 <	11 ~ 15	16 ~ 20	21 <
Number of sample	1	16	17	55

Table 2 | The distribution of sampled GSPs according to diameter

Diameter (mm)	15	20	25	32	40	50	65	80
Number	36	5	14	8	3	15	7	1

Examination with visual assessment

In order to evaluate the condition of the sampled pipes, direct diagnosis including examination with the visual assessment, analysis of the pipe body and the measurement of the thickness were conducted in this study. Table 3 explains the visual assessment in detail. Both internal and external assessment items and contents of aged service pipes were selected from literature reviews and results of field investigation (Treado 1997; Kazhide 2000; Lee *et al.* 2002*a*, 2002*b*; Tosimi 2002). Describing in more detail, each

Table 3 | Visual assessment

The internal		State of corrosion
	Related products of corrosion	Size of tubercles
		Hydraulic cross sectional area reduction (%)
The external		**State of corrosion**
	Related products of corrosion	Ratio of external corrosion area
		Accumulation of corrosion products
	Deterioration	Horizontal crack
		Pit corrosion (Hole)

tubercle size was measured using vernier calipers. In addition, in order to calculate hydraulic cross sectional area reduction rate, the sampled pipe was cut off into 10 cm pieces and then its volume and inner diameter were measured using mass cylinder and vernier calipers, respectively. For the unused same size pipe, its volume and inner diameter were measured. Each hydraulic cross sectional area could be calculated from its volume and inner diameter.

Analysis of physical properties and chemical compositions

Analysis of pipe body, including strength test and chemical assay, was conducted to investigate physical properties and chemical compositions. Physical properties including Hardness were investigated by KS B 0802 (Korean Standard, Metal material tensile strength test) as shown in Table 4. Also, a chemical composition assay was focused on phosphorous and sulfur (refer to Table 5). For comparison of chemical compositions according to water basin, age of pipe and diameter, inductively coupled plasma (ICP) was used for analyzing each scale chemically.

Assessment of corrosion rate by measuring pipe thickness

In order to evaluate the corrosion rate, the remaining thickness of the sampled pipes was measured using ultrasonic thickness meter (WT 630, Worldtech).

Table 4 | Standards of physical properties on GSPs (KS D 3537)

Items	Tensile strength (N/mm^2)	Elongation (%)	Hardness (HRB)
Standard of GSP	294 <	30 < (for 11, 12 test piece)	–
		25 < (for 5 test piece)	–

Table 5 | Standards of chemical composition on GPSs (%) (KS D 3537)

Items	Phosphorous	Sulfur
Standard of GSP	0.040 <	0.040 <

RESULTS AND DISCUSSION

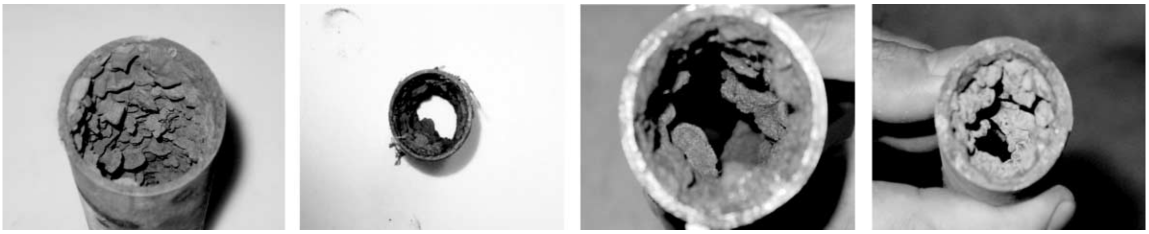
The results of visual assessment

When most of the sampled pipes were examined, visual assessment showed (visual assessment) that corrosion on the external surface of each pipe scarcely could be seen. The reason for this result is that most of the water service pipes in buildings are laid in concrete walls, or covered with anticorrosive paints. Therefore even though those pipes are exposed to the atmosphere, they are not significantly influenced by corrosion.

On the internal surfaces of the sampled pipes, the tubercle growth and the hydraulic cross sectional area reduction were observed. Although laying conditions were identical (e.g. sampled from same apartment), hydraulic cross sectional areas are different from each other according to age of pipe (Figure 1).

Figure 2 shows the results of visual assessments according to major water basins, age of pipe, and diameter. As shown in Figure 2(a), the size of tubercle in pipes sampled from three water basins was 0.1 ~ 20 mm, the reduction rate of hydraulic cross sectional area was 5 ~ 100%, and ratio of the external corrosion area on the sampled service pipes was 0 ~ 100%. There was little difference among main water basins. The number of horizontally cracked pipes was 6 on Han River Basin(HRB), 4 on Nakdong River Basin(NRB) and 2 on Dongbuk Lake Basin(DLB). Also, the number of sampled pipes that had pit corrosion (holes) were 6 on HRB, 1 on NRB and 0 on DLB, respectively.

As shown in Figure 2(b), the size of tubercle, the decline of hydraulic cross-sectional areas and the ratio of external corrosion areas on the pipes depending on the age of pipe do not show distinct trends. Because of the limited data set, it was very hard to conclude a concrete relationship between the age of pipe and other parameters. The number of horizontally cracked pipes was 4 in the case of pipes 16 ~ 20 years; 8 in the case of those over 21 years. Accordingly the relationship between the number of cracked pipes and the age of pipe is somehow proportional. From the view of pitting corrosion (hole), the number is 1 in the case of pipes 16 ~ 20 years, and 6 in the case of those



(a) 10 Years (b) 13 Years (c) 17 Years (d) 25 Years

Figure 1 | Representative examples of water service pipes (galvanized steel pipes) according to age of pipe.

over 21 years. The number of pitting corrosion on the pipes (hole) tends to be proportional to the age of pipe.

As shown in Figure 2(c), as the diameter of the pipe increases, the size of tubercle increases. On the other hand, as the diameter of the pipe decreases, the decline of hydraulic cross-sectional area becomes more serious, and the occurrence of cracked and pitting corrosion on the pipes becomes more frequent. Therefore it can be

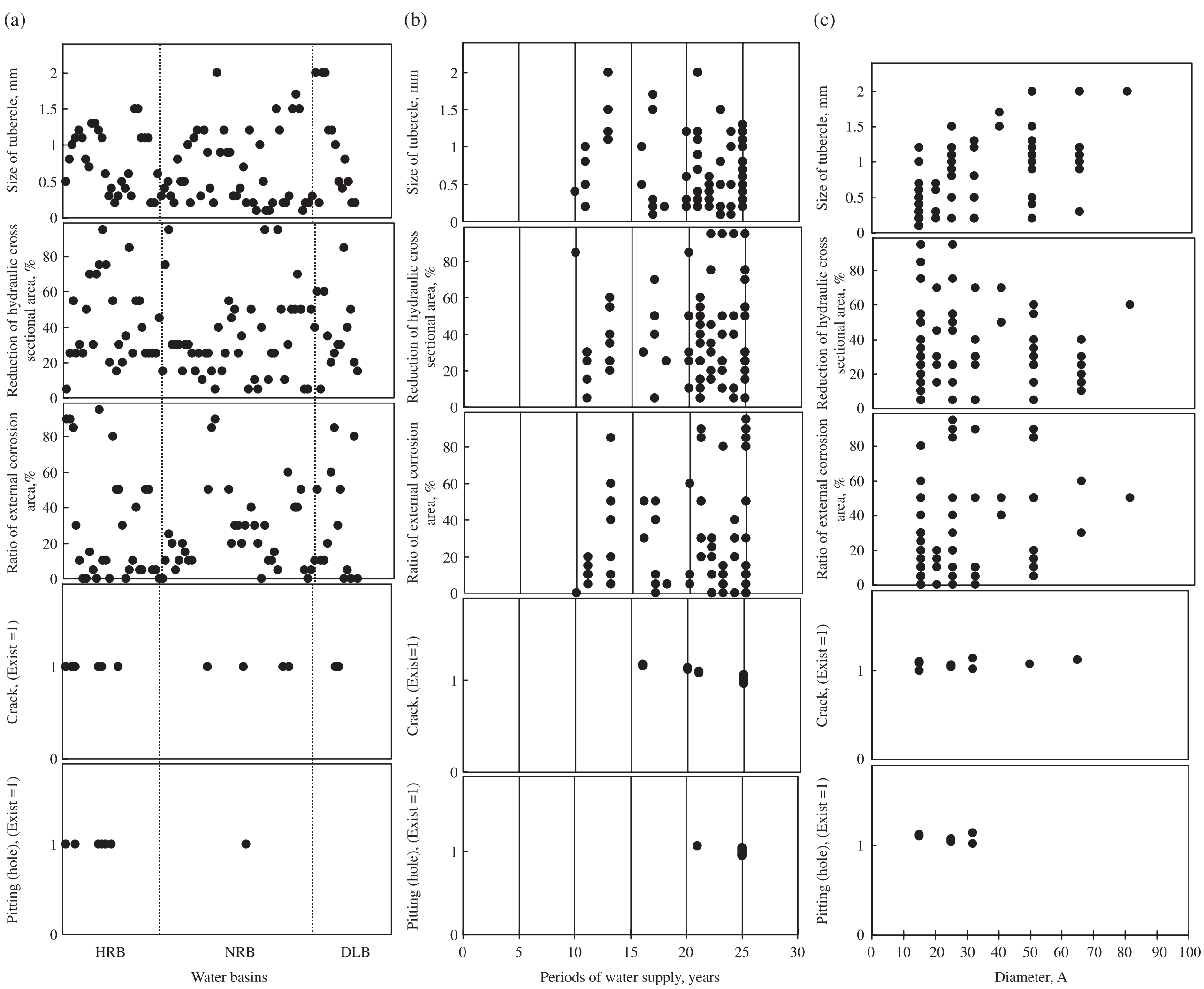


Figure 2 | Visual assessment results on sampled GSPs (HRB: Han River Basin, NRB: Nakdong River Basin, DLB: Dongbuk Lake Basin, Diameter, A: (mm)).

concluded from visual assessment that the smaller the diameter of pipe, the more serious the deterioration.

Taking into account the results of visual assessments, Figure 3 shows the growth rate of tubercle and the decline rate of hydraulic cross-sectional area based on water basins, the age of pipe and the diameter of pipe. As shown in Figure 3(a), the diameter of pipe affects seriously the decline rate of hydraulic cross-sectional area. However, there is little difference among water basins. Also, from Figure 3(b), it is observed that the growth rate of tubercle and the decline rate of hydraulic cross-sectional area in the case of pipes 10 ∼ 15 years are higher than those of over 16 years. These results indicate that the growth rate of tubercle and the decline rate of hydraulic cross-sectional area are dependant on the age of pipe. Although both rates increase sharply in the early period from starting water supply, as the age of a pipe increases, those rates decrease gradually.

Investigating the growth rate of tubercle and the decline rate of hydraulic cross-sectional area as can be seen in Figure 3(c), the growth rates of tubercle in the pipes of over 40 mm diameter are relatively higher than those in the pipes of less than 40 mm diameter, but the decline rates of hydraulic cross-sectional capacity in each pipe are alike, or even the decline rate in the pipes of over 40 mm diameter are lower. The results are due to a larger cross-section of pipe providing more sufficient space for the growth of tubercle. However, comparison between the cross-section area of pipe and the area occupied by tubercle, the latter is too small to affect total cross-section area.

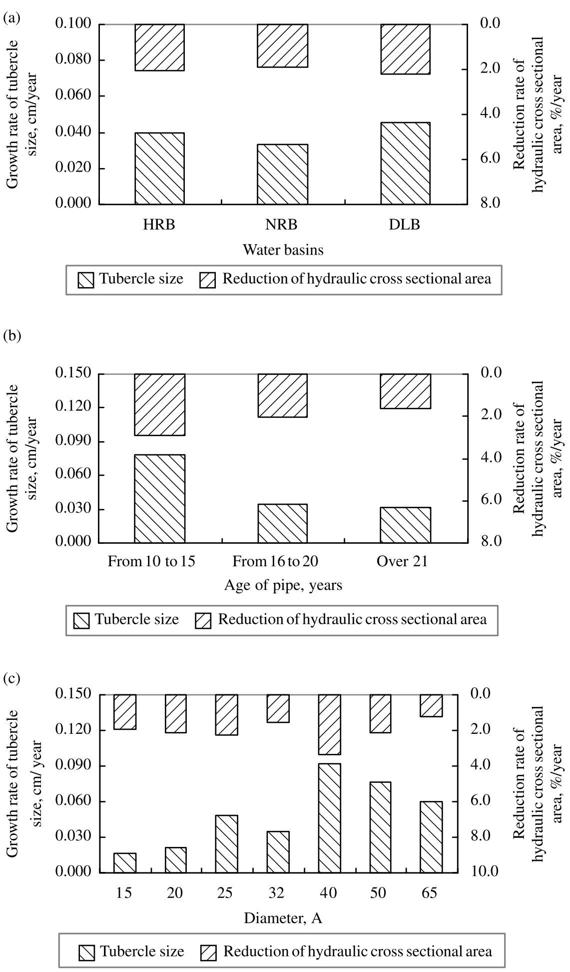


Figure 3 | Growth rate of tubercle size and decline rate of hydraulic cross-sectional capacity.

Analysis of physical properties and chemical compositions

Generally, there are various parameters that affect the deterioration of the pipe body as mentioned above. Especially, in the pipe that cannot meet the standard requirements, the deterioration such as corrosion or cracks progress more rapidly than in the pipe that meets the requirements. Accordingly, through analysis of physical properties and chemical compositions, the healthiness of the incipient stage can be diagnosed. Also the effect of corrosion from aging on physical properties of pipes can be assessed.

Figure 4 shows the analysis results of physical properties including tensile strength and elongation according to water basins, the age of pipe and the diameter of pipe. Actually, it is difficult to acquire sufficient information about the physical properties at the incipient stage. From the measurement of the tensile strength and elongation of sampled pipes, about 13.4% among total pipes meet the Korea Standard tensile strength requirements for water supply pipe (less than 294 N/mm^2). Since over 90% cannot meet the Korea Standard elongation requirement, a lowering of strength accelerated by corrosion appears mostly.

Accordingly, it can be thought that elongation is more affected by aging than any other physical properties. Referring to the average elongation values according to the age of pipe as seen in Figure 5, the average elongation value of a pipe whose

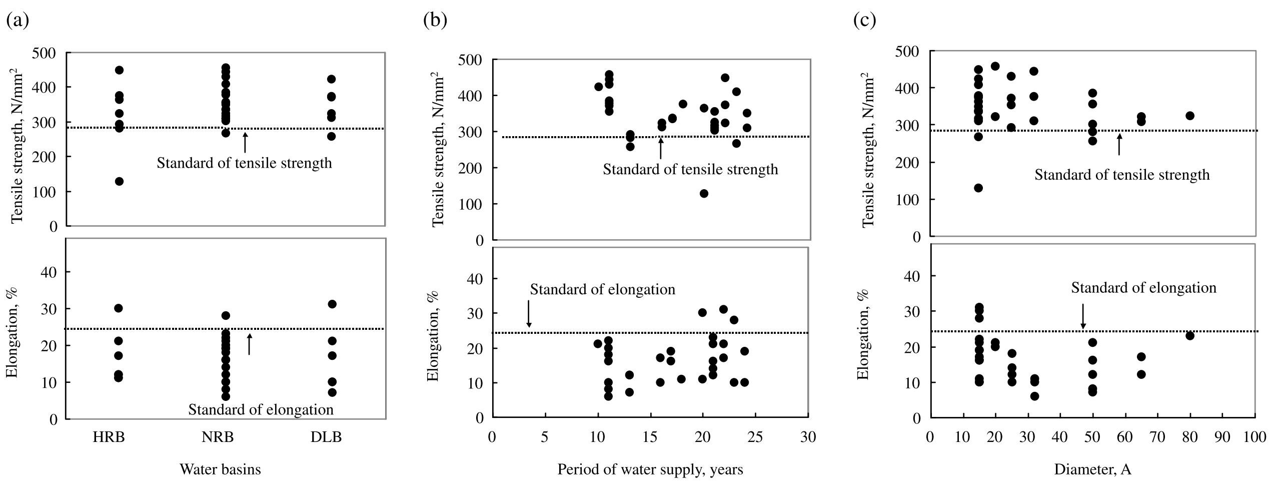


Figure 4 | Results of physical properties analysis.

age is over 10 years is about 14 ~ 16%, and 36 ~ 40% less than the standard requirement.

Figure 6 shows the analysis results of chemical compositions according to water basins, the age of pipe and the diameter. In the case of galvanized steel pipes there are only two standard items for chemical compositions regulated by Korean government, those are phosphorous (P) and sulfur (S). Both contained quantities should be less than 0.040%. From the analysis results in Figure 6, P and S quantities in most of sampled GSPs are measured to be less than the regulated value, 0.040%. Therefore it can be concluded that there is little effect of chemical composition on the deterioration of a water supply pipe.

Analysis of scale compositions

Figure 7 shows the contained quantities of iron (Fe) and Zinc (Zn) among the ingredients of scale formed in pipes

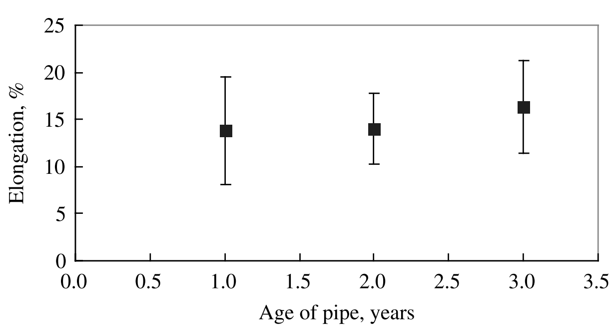


Figure 5 | Average elongation value according to the age of pipe.

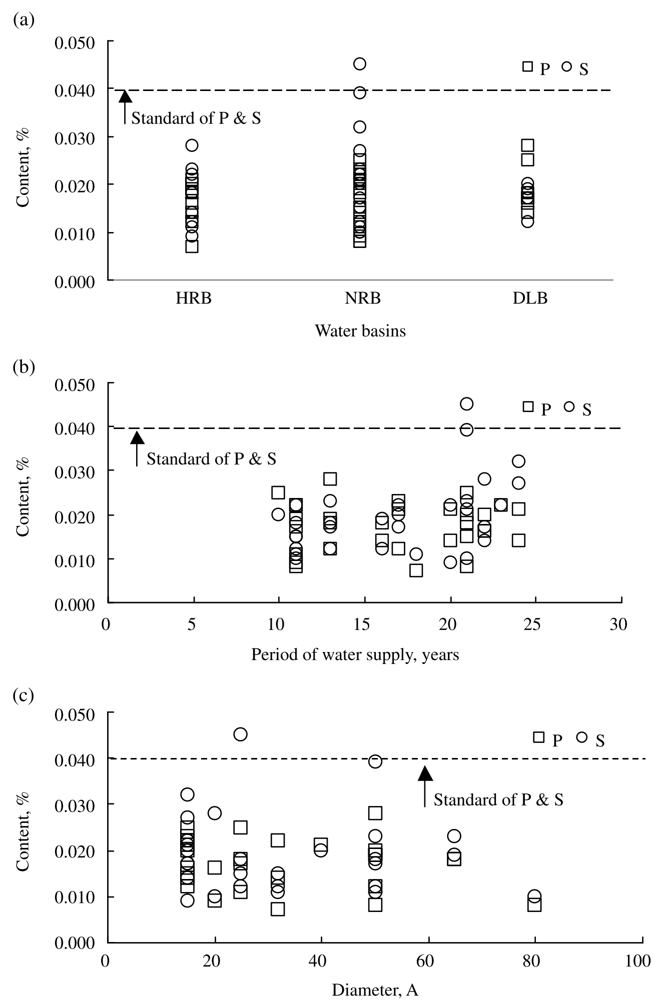


Figure 6 | Results of chemical composition analysis.

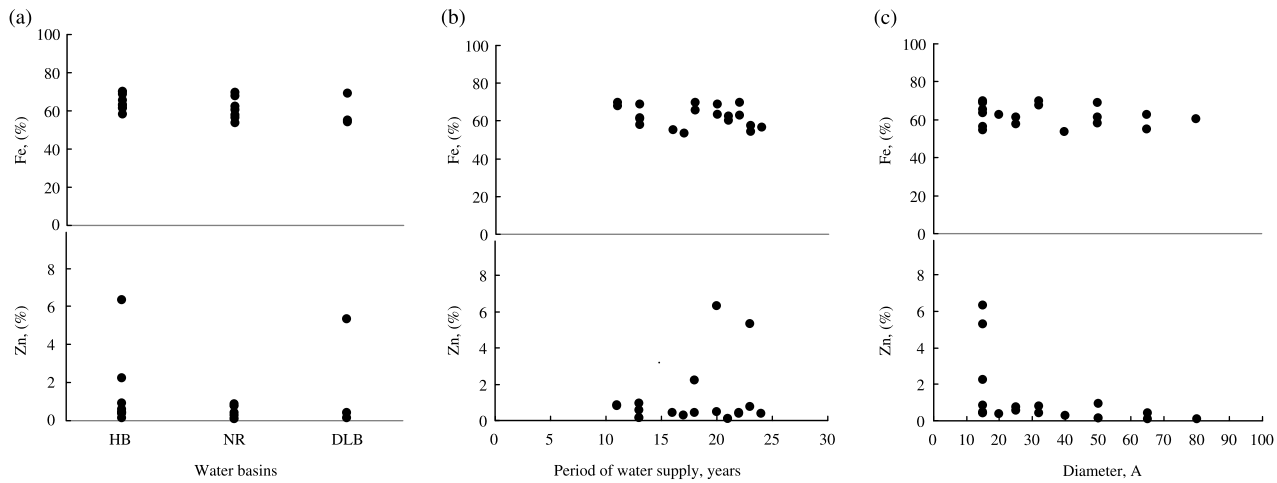


Figure 7 | Results of scale composition analysis.

sampled according to water basins, the age of pipe and the diameter. Even though other inorganic materials are eluted from the scale in addition to Fe and Zn, the amount of those is too small to consider. As shown in Figure 7, the contained quantity of Fe, which is the largest among the ingredients, is 54.3 ~ 69.8%. However, the contained quantities of Fe and Zn were not different according to water basins, the age of pipe and the diameter. In the case of Zn, the contained amount is 0.09 ~ 6.34%. In the aged and small sized pipe whose diameter is less than 15 mm, the contained amount of Zn tends to be higher than in other cases. In the case of pipes in which Zn amounts are high, the decline rate of hydraulic cross-sectional capacity is generally lower than in the case in which Zn amount is low. Also, the occurrence frequency of crack and pitting in the former case is lower than in the latter case. These results indicate that the state of galvanization on the internal wall is significantly related to the degree of aging the pipe.

The results of corrosion rate assessment by measuring thickness

Figure 8 depicts the thickness reduction percentages derived from minimum and average remaining thickness

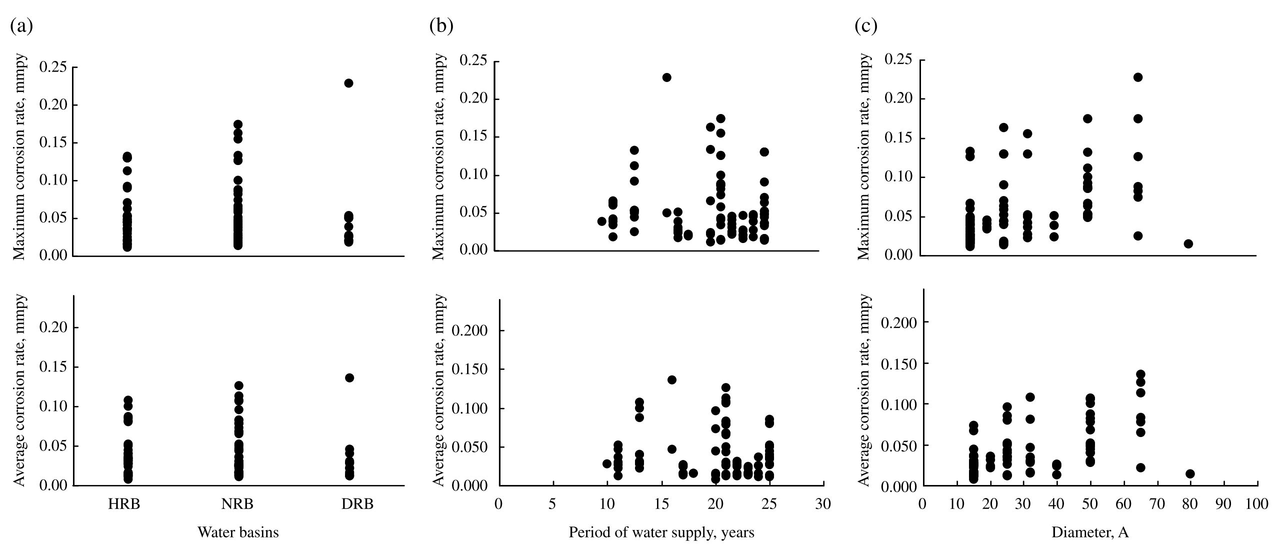


Figure 8 | Results of maximum and average erosion percent on sampled GSPs.

of the sampled pipes. From the measurements of minimum and average remaining thickness, although a little external corrosion could be seen with the unaided eye, the reduction of thickness due to that could be negligible. The reduction of thickness by external corrosion was not taken into account. As seen in Figure 8 the distributions of average and maximum thickness reduction rates depending on water basins and diameters are presented to be wide, and both the reduction rates become somewhat higher as the age of pipe is longer.

Figure 9 shows the average corrosion rates based on the thickness reduction percentages depending on water basins,

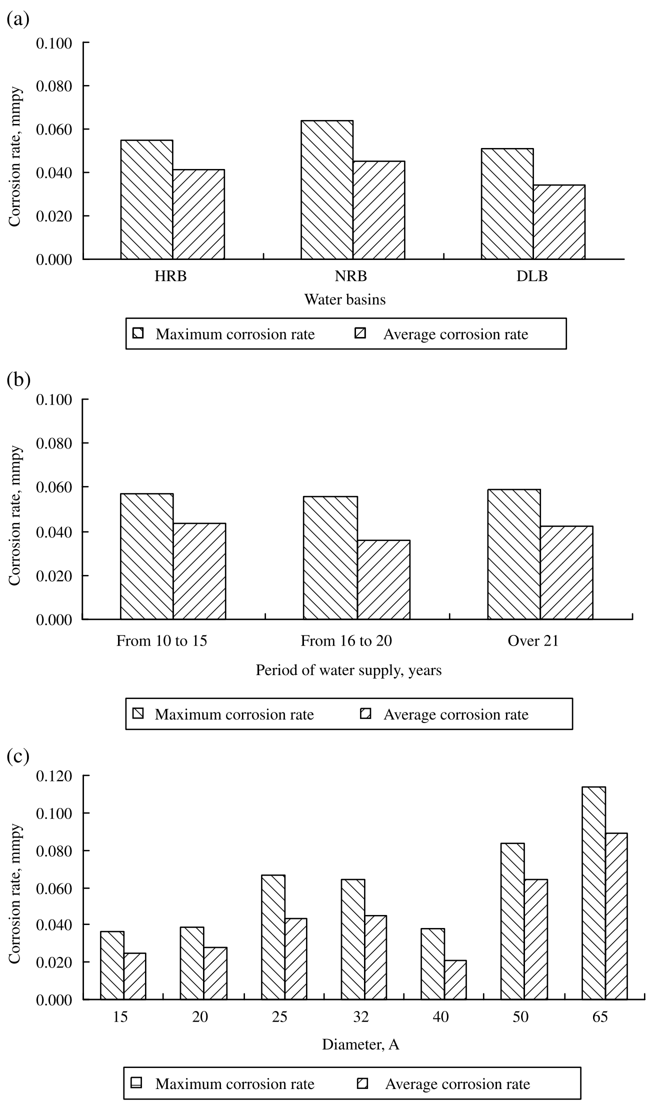


Figure 9 | Maximum and average corrosion rates.

Table 6 | Evaluation of corrosion intensity by corrosion indices

	Corrosion indices	
Water basins	**LI**	**LR**
HRB	− 0.72	0.84
NRB	− 0.85	1.51
DLB	− 0.74	0.94

age of pipe and diameters. Figure 9(a) expresses that the maximum corrosion rate in NRB was calculated as 0.064 mmpy, 0.055 mmpy in HRB, 0.051 mmpy in DLB. These results were in good accordance with Lee' researches that the corrosion rate in NRB is relatively higher than those in other basins. Lee *et al.* (2002*a*, 2002*b*) revealed that Nakdong-river has the lowest LI(Langelier Index) and the highest LR(Larson Ratio) compared with other rivers (Lee *et al.* 2002*a*, 2002*b*) as shown in Table 6.

Investigating the maximum corrosion rate depending on the age of pipe as seen in Figure 9(b), there is little difference, and the corrosion rates are 0.056 ~ 0.059 mmpy. These results did not correspond to the trend of thickness reduction percentages seen in Figure 8. This is due to the fact that the age of pipe was taken into account for deriving the corrosion rate.

From the comparison of each corrosion rate depending on diameters, as diameters increase with the exception of 40 mm pipe, both the maximum and average corrosion rate become higher. For example, the maximum corrosion rate in 15 mm pipe was calculated as 0.036 mmpy. And that in a 65 mm pipe was 0.114 mmpy, which is 3 times as high as the corrosion rate in the 15 mm pipe.

SUMMARY

In this study, we sampled and assessed water service pipes made of galvanized steel in buildings by the direct diagnosis according to major water basins, age of pipe, and diameter. The main conclusions drawn from this study are as follows:

(1) From the results of visual assessments according to major water basins, age of pipe, and diameter, the size

of tubercle and the hydraulic cross sectional capacity reduction rate were similar with each other among main water basins. Also, the growth rate of tubercle and the decline rate of hydraulic cross-sectional capacity in the case when the age of the pipe is 10 ~ 15 years are higher than those of over 16 years. The growth rates of tubercle in pipes of over 40 mm diameter are relatively higher than those in pipes of less than 40 mm diameter, but the decline rates of hydraulic cross-sectional capacity in each pipe are alike, or even the decline rate in pipes of over 40 mm diameter are lower.

(2) It was investigated from the results of pipe body analysis that over 90% cannot meet the Korea Standard elongation requirement; a lowering of strength accelerated by corrosion appears mostly. In addition, referring to the average elongation values according to the age of the pipe, the average elongation value of a pipe whose age is over 10 years is about 14 ~ 16%, and 36 ~ 40% less than the standard requirement. From analysis of scale compositions, the contained quantity of Fe, which is the largest among the ingredients, is 54.3 ~ 69.8%. In the aged and small sized pipe whose diameter is less than 15 mm, the contained amount of Zn tends to be higher than in other cases.

(3) From the results of corrosion rate assessment by measuring thickness, the maximum corrosion rate in Nakdong River Basin (NRB) was calculated as 0.064 mmpy; 0.055 mmpy in Han River Basin (HRB) and 0.051 mmpy in Dongbuk Lake Basin (DLB). Also, investigating the maximum corrosion rate depending on the age of the pipe, there is little difference, and the corrosion rates are 0.056 ~ 0.059 mmpy.

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