Statistical Analysis on Sewer Pipe Characteristics and Occurrence of Ground Cave-ins

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***Abstract* — A damaged sewer pipe is considered a major cause of the occurrence of urban ground cave-ins. Identifying the sewer pipe characteristics that contribute to the occurrence of ground cave-ins can be highly helpful in detecting the damaged sewer pipes and preventing ground cave-ins. To achieve this aim, Student's t-test and chi-square test were performed with all the sewer pipes in Seoul that included the ground cave-in occurrence and nonoccurrence cases.**

Keywords* — *ground cave-ins; damaged sewer pipe; Student's t-test; chi-square test

I. INTRODUCTION

Numerous ground cave-ins induced by a damaged sewer pipe have been reported from many urban areas in the U.S., Japan, and South Korea [1]-[3]. Japan National Institute for Land Infrastructure Management (JNILIM) reported that about 17,000 ground cave-ins occurred in Japan between 2006 and 2009 [2]. In Seoul, 3,626 cases of ground cave-ins were reported between 2011 and 2015 [3]. Extensive inspection using a video camera robot and a ground penetrating radar (GPR) is required for detecting and replacing the ruptured sewer pipes to prevent ground cave-ins [4][5], but most of the big cities in the world run thousands of sewer pipes beneath the streets. Seoul, for example, runs 370,000 sewer pipes, with a total length of approximately 10,000 km [3]. The massive number of sewer pipes running beneath the streets makes their inspection practically impossible. For their efficient inspection, suspicious sewer pipes and the surrounding area that may induce ground cave-ins should be preferentially investigated. To achieve this aim, the sewer pipe characteristics that may contribute to the occurrence of ground cave-ins need to be determined.

JNILIM and Davies et al., [2][6] investigated the relationship between the sewer pipe characteristics and the occurrence of ground cave-ins. The previous researches, however, considered only the ground cave-in occurrence cases and did not consider the ground cave-in nonoccurrence cases. But studies on nonoccurrence group, together with occurrence group, can also provide meaningful implication for ground cave-in occurrences. In this study, for the ground cave-in occurrence and nonoccurrence groups, comparative analysis (i.e., Student's t-test, chi-square test) was performed.

The statistical analysis including data acquisition and analysis method are laid out in section 2. Section 3 presents and discusses the statistical analysis results and section 4 summarizes the contributions and conclusions of this study.

II. MATERIALS AND METHODS

The sewer pipe database built by the Seoul metropolitan government provides the characteristics of each of the sewer pipes buried in Seoul (221,242 cases). Using Google map, the addresses of the ground cave-ins obtained via the ground cave-in reports (968 cases) were converted to TM coordinates. With the coordinates of ground cave-ins and the sewer pipe database, damaged sewer pipes were identified and assigned to the ground cave-in occurrence group, and the remaining sewer pipes were assigned to the ground cave-in nonoccurrence group by using nearest sample tool in QGIS 2.14.4. R, a language for data analysis was used to analyze the obtained data. Based on the previous researches, the sewer pipe characteristics that were to be tested for their contribution to the occurrence of ground cave-ins were chosen.

For the continuous variables, six sewer pipe characteristics (i.e., length, average burial elevation, average burial depth, height difference between the two ends, equivalent radius of the cross-sectional area, and operating duration of the sewer pipe) were selected. Independent Student's t-test with the null hypothesis "the means of the two groups are the same" was performed to determine if there was a significant difference between the mean of the ground cave-in occurrence group and that of the ground cave-in nonoccurrence group [7]. Applying Student's t-test, a pooled two-sample t-test was performed when the assumption of homogeneity of variances was available, whereas an unpooled two-sample t-test was performed when the assumption was not available [8]. To assess the homogeneity of variances, the Levene test was performed [9].

For the categorical variables, two sewer pipe characteristics (i.e., cross-sectional shape and material of the sewer pipe) were selected. A chi-square test with the null hypothesis "the two categorical variables are independent" was performed to determine if the explanatory and response variables were independent [10].

III. RESULTS AND DISCUSSION

Table I summarizes the results of the analyses of the Levene test for the homogeneity of variances and of the Student's t-test performed for the continuous variables. For the average burial elevation, average burial depth, and operating duration of the sewer pipes, which showed a less than 0.05 p-value in the Levene test (i.e., not available for homogeneity assumption), an unpooled two-sample t-test was performed. On the other hand, a pooled two-sample t-test was performed for the length, height difference between the two ends, and equivalent radius of the cross-sectional area of the sewer pipes, which showed a higher than 0.05 p-value in the Levene test. The length, average burial elevation, average burial depth, and operating duration of the sewer pipes showed a far lower than 0.05 p-value in the t-test, which implies that there was a highly significant difference in mean between the ground cave-in occurrence and nonoccurrence groups. On the other hand, the height difference between the two ends and the equivalent radius of the cross-sectional area of the sewer pipes showed a higher than 0.05 p-value in the Student's t-test, which implies that there was no significant difference in mean between the ground cave-in occurrence and nonoccurrence groups. Based on the results of the Student's t-test and the mean values of the ground cave-in occurrence and nonoccurrence groups, it can be concluded that the susceptibility to the occurrence of ground cave-ins increases as the length and operating duration of the sewer pipe increases and as the average burial elevation and average burial depth of the sewer pipe decrease.

Table II summarizes the results of the analysis of the chi-square test results. The equivalent radius of the cross-sectional area of the sewer pipe, whose p-value was higher than 0.05, was independent of ground cave-in occurrence. On the other hand, the material of the sewer pipe was dependent on ground cave-in occurrence because its p-value was lower than 0.05.

IV. CONCLUSIONS

This study investigated the sewer pipe characteristics that contribute to the occurrence of ground cave-ins by performing Student's t-test and a chi-square test on the ground cave-in occurrence and nonoccurrence groups. Based on the analysis results, the conclusions shown below were drawn.

(a) In the case of the continuous variables, the length, average elevation, average burial depth, and operating duration of the sewer pipes showed significant differences in mean between the ground cave-in occurrence and nonoccurrence groups. In other words, there is evidence that longer or older pipes are damaged more often, which may have contributed to ground cave-in. Additionally, the pipes with lower burial depth and lower average elevation also induce ground cave-in more frequently.

(b) In the case of the categorical variables, the material of the sewer pipe showed a significant correlation with ground cave-in occurrence, while pipe shape did not.

Student's t-test and chi-square test, however, have limitation that they only deal with mean difference independence. To find a specific correlation between the sewer pipe characteristic and the occurrence of ground cave-ins, further research including regression analysis need to be performed.

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TABLE I. RESULTS OF THE LEVENE TEST AND STUDENT'S T-TEST

Variables	**Mean**		**Std deviation**		**Levene test**		**Student's t-test**	
	Non-occurrence	*Occurrence*	*Non-occurrence*	*Occurrence*	*F*	*p-value*	*t*	*p-value*
Length (m)	31.35	47.14	31.54	32.67	1.936	0.164	-15.541	1.961×10^{-54}
Operating duration of sewer pipe (year)	20.65	22.47	11.73	11.45	17.405	0.000	-4.932	9.539×10^{-7}
Average elevation (m)	26.96	24.78	18.40	14.67	31.230	0.000	4.592	5.000×10^{-6}
Average burial depth (m)	1.01	0.97	0.72	0.48	25.226	0.000	2.700	7.000×10^{-3}
Equivalent radius of cross-section (m)	0.67	0.69	0.52	0.48	0.122	0.726	-1.358	0.175
Height difference between the two ends (m)	0.30	0.32	0.60	0.53	0.411	0.522	-1.099	0.272

TABLE II. RESULTS OF THE CHI-SQUARE TEST

Variables		**No. of sewer pipes**		**chi-square test**	
		Occurrence	*Nonoccurrence*	*chi square*	*p-value*
Sewer pipe material	Hume pipe	190,349 (99.6%)	848 (0.4%)	37.980	3.800×10^{-7}
	Concrete box	16,523 (99.6%)	65 (0.4%)		
	Wrinkled tube	4,238 (99.1%)	39 (0.9%)		
	Concrete pipe	2,621 (99.8%)	6 (0.2%)		
	PE pipe	2,467 (99.9%)	3 (0.1%)		
	Other	4,076 (99.8%)	7 (0.2%)		
Sewer pipe cross-sectional shape	Circular	203,587 (99.6%)	903 (0.4%)	1.020	0.312
	Rectangular	16,687 (99.6%)	65 (0.4%)		

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