Risk Analysis of ground subsidence using Sewer GIS Data

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ABSTRACT

The risk of road subsidence occurring around big urban areas is increasing, due to unsystematic construction of transportation systems, such as subways or underground roadways, as well as public infrastructure, such as water supply and drainage pipes, communication systems, or electricity supply systems. In particular, as the aging of those facilities has recently accelerated, the frequency of occurrence and the risk of subsidence have been increasing. Especially, more than 80% of the subsidence events around Seoul resulted from damaged sewer. In order to prevent this, a close examination of the sewer pipe is necessary. However, faced with the extensive and constant risk of road subsidence, direct investigation of facilities has been limited by the restricted time and budget. Thus in this study, by using sewer GIS information, we analyzed the correlations between road subsidence and pipeline ID, with year of construction, pipeline type, pipeline diameter, pipeline length, pipeline burial depth, results of investigation, removal system, management agent. Through this analysis influence factors that could be utilized in the risk evaluation were identified. The results of correlation analysis between sewer information and subsidence occurrence in Seoul indicated that the pipe type, pipe diameter, burial year, and removal system are highly correlated with road subsidence. Also, Analytic Hierarchy Process (AHP) were conducted using the chosen influence factors to determine the optimal analysis method, as well as evaluation method, thereby suggesting condition evaluating methodology for predicting road subsidence. When weights were calculated by using AHP analysis, the weight of burial year was the largest, followed by those of pipe type, maintenance control, lane passage number, removal system, and pipe diameter. Finally to evaluate the obtained weights and analysis method through AHP, GIS tool was used to check the sewer condition in the area where the actual sinkhole occurred. Concluded that the suggested risk assessment method is valid for predicting road subsidence. Thus, the analyses above are expected to increase the accuracy of determining priority for sewer repairs, as well as assess the risk of road subsidence.

Keywords: Risk Analysis, Sinkhole, Ground Subsidence, Sewer, GIS

1 INTRODUCTION

Recently, ground collapse phenomenon occurs frequently in urban area of Korea. In particular, it has been reported that the aging of sewer pipe is accelerated and the risk of ground collapse increases at surrounding ground of defective sewer pipes (Lee et al, 2015.) In Seoul City from 2010 to 2015, more than 3,000 ground collapse have occurred, and 80% of the incidences is due to the damage of sewer pipelines. In this study, the risk of ground collapse was analyzed according to the characteristics of sewer pipe by utilizing sewer GIS data. The correlation studies between ground collapse and installed period, structural type, and diameter of sewer pipes were performed. In addition, AHP (Analytic Hierarchy Process) was conducted with experts' survey by adding the road condition where the pipe is buried and the sewer maintenance history, and finally a ground collapse risk evaluation method with related to the condition of sewer pipe is proposed. Comparative analysis was conducted between the occurred ground collapses in a specific area of Seoul and the evaluation result of the ground collapse risk using sewer pipe information in the area. As a result, the applicability of the proposed evaluation method was verified

2 INFLUENCING FACOTRS FOR GROUND COLLAPSE AROUND UNDERGROUND SEWER PIPELINE

Table 1 shows sewer GIS data. GIS data is composed of pipeline management information, pipe specification, buried ground information, and drainage water information together with geographical properties. The main influencing factors were extracted to confirm the relationship between GIS data and ground collapse. The influencing factors considered in this study are the installation period, the pipe diameter, the pipe type, the depth of burial, and the drainage system condition.

As of 2016, Seoul has 160,300 km of sewer pipelines. In Seoul, 3,266 ground subsidence occurred from 2010 to 2015. Figure 1 shows the installation status of the sewer line and the location of the ground collapse incidences. Various causes of ground collapse are reported, but more than 80% of them have been reported to be caused by sewer pipe damage or defect. Therefore, the correlation between the collapse and the characteristics of sewer pipe which is located nearest to the incidence is analyzed.

Fig. 1. Sewer Line and ground subsidence point(GIS Data)

Table 1. Sewer layer of underground space integrated map

List	Item
Sewer Management Information	Topography Mark, Management Number, Area Code, Map Number, Management Agency Code, Construction Number, Start and End Point Manhole Management Number
Sewer Data	Installation Data, Sewer Expense, Texture, Scale, Conformation, Pipe Size, Extension
Sewer Burying Information	Start and End Point , sewer invert elevation Mean Slope, Lane Passage Number
Sewer Discharge Information	Storm and Sewage Drainage Area, Velocity of Flow

2.1 Sewer Installation Date vs. Ground Collapse

The relationship between the buried period of sewer line managed by Seoul and the location of ground subsidence was analyzed. Figure 2 shows the installation period of the sewer pipeline and the rate of occurrence of the ground subsidence. The x-axis represents the installation period of the sewer line and the y-axis represents the rate at which the ground subsidence occurs. The rate of occurrence for ground collapse is the ratio of the number of unit pipes in the period and the number of ground collapse around the pipeline. If the installation date of the sewer pipe is not known, it was filled in the GIS DB in 1900. As described above, 30% of the 160,000 km of sewage pipes installed in Seoul is equivalent to this. In this case, the installation period was estimated to be over 40 years. It can be seen that the longer the installation period of the sewer pipe, the greater the incidence of the ground subsidence. If the installation period is more than 40 years, the occurrence rate of the ground subsidence decreases because the previously unknown data of the buried period are reflected in the analysis results.

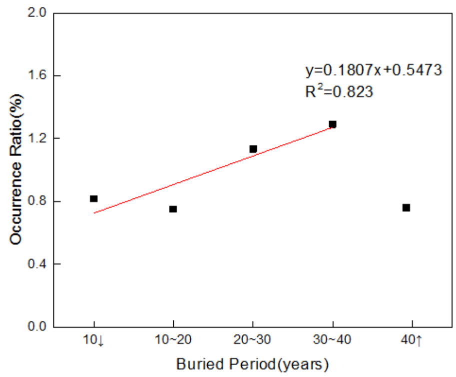

Fig. 2. Road subsidence in relation to the burial period of sewer

2.2 Sewer Pipe Diameter vs. Ground Collapse

Figure 3 shows the correlation between the diameter of the sewer pipe and the incidence of ground subsidence. In the figure, the x-axis is the diameter of the sewer pipe and the y-axis is the rate of occurrence of the ground subsidence. The rate of occurrence is the ratio of the number of ground subsidence around the sewer pipe to the number of sewer pipes of that diameter. As the diameter of sewer pipe increases, the rate of occurrence of ground subsidence becomes larger in general.

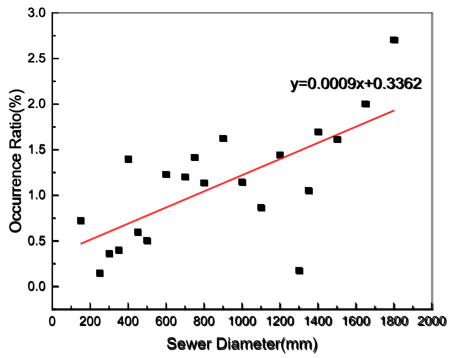

Fig. 3. Correlation between the sewer diameter and subsidence

2.3 Sewer Pipe Structural Type vs. Ground Collapse

There are four kinds of structural pipe types in Seoul as shown in Fig. 3. Table 2 shows sewer ratios and ground subsidence rates for different pipe types. The HP pipe was 88.2% of the sewer pipe, the RC-BOX pipe was 8.5%, the THP pipe was 2%, the PVC pipe was 0.9%, the GRP pipe was 0.4%, and the DCIP pipe was 0.01%. About 400 sewer pipes were not used for analysis due to unknown or minor pipe type. The type of sewer where the ground subsidence occurred the most is HP (92%). The results show that the number of different types of sewers and the number of ground subsidence are correlated. However, in the case of Hume pipe, the ratio of ground subsidence occurrence was about 4% higher than the ratio of sewer number. This is because durability is relatively low compared to other types of pipes.

Table 2. Sewer layer of underground space integrated map

Sewer Type	Number of sewers	Ratio (%)	Number of sewers closest to subsidence	Ratio (%)
HP	299,164	88.2	2,658	92.1
PVC	2,921	0.9	7	0.2
RC-Box	28,913	8.5	148	5.1
GRP	1,474	0.4	11	0.4
DCIP	139	0.0	1	0
THP	6,627	2.0	60	2.0
Total	339,238	100	2,885	100

2.4 Sewer Pipe Buried Depth vs. Ground Collapse

The depth of the sewer pipe near the ground subsidence is mostly less than 1 m and the proportion is 60%. About 34% for 1m ~ 2m, about 3% for 2m ~ 3m, about 1% about 3 ~ 5m and about 0.5% about 5m were identified. As shown in Table 3, the buried depth of the sewer pipe was mostly 1 m. Therefore, the depth of burial was less correlated with ground subsidence.

Table 3. Sewer burial depth in Seoul

Burial Depth	Number of sewers	Ratio (%)	Number of sewers closest to subsidence	Ratio (%)
above 5 m	1,554	0.4	18	0.5
(3–5) m	6,261	1.6	40	1.2
(2–3) m	16,386	4.3	108	3.3
(1–2) m	105,108	27.7	1,115	34.2
below 1 m	250,743	66.0	1,984	60.8
Total	380,052	100	3,265	100

2.5 Drainage System Type vs. Ground Collapse

The sewer drainage system types in the city of Seoul are the combined box culvert, open channel, side gutter, combined pipe, storm pipe, sewer pipe, sewer box culvert, interceptor pipe, inlet pipe connecting line, and interceptor box culvert. This can be broadly classified into three types. The three types are divided into combined (strom & sewer) pipe, storm pipe, and sewer pipe. The drainage method of the sewer pipeline near the ground subsidence occurrence area is the combined (92.8%), the storm (2.48%), and sewer (4.74%).

3 AHP ANALYSIS FOR INFLUENCING FACOTRS TO GROUND COLLAPSE

Based on the information of the sewer line around the site of the ground subsidence in Seoul, its correlation with the ground subsidence was studied. The analysis showed that the pipe type, pipe diameter, burial period, and drainage type showed a high correlation. About 95% of the sewer lines are buried within 2m. The installation depth and Pearson correlation coefficient of the ground collapse were low as 0.2 and excluded in the evaluation factors. In addition, as additional factors that could indirectly affect the soundness of the road, the road status (number of lanes / national highway or freeway) and the maintenance status (the inside sewer survey) were considered.

AHP analysis is a technique for determining the relative importance of proposed Influencing factors. The analysis factors used in this study are as follows.

- Factor 1: Structural type of Pipe
- Factor 2: Pipe diameter
- Factor 3: Installation period
- Factor 4: Drainage system (Combined, Storm, and Sewer)
- Factor 5: Road status above the buried sewer
- Factor 6: Maintenance history information

As a result of AHP analysis, the importance of factors affecting ground collapse was found in the order of installation years → pipe type → maintenance history → surrounding road condition → drainage system type → pipe diameter. The weight of each factors is shown in Table 4.

In order to verify the applicability of the proposed method, the nearest sewer pipe at the point of incidences for the S-district of Seoul was analyzed to find the risk of ground collapse. The results of the analysis show that E and F grades, which are the risk grades, are over 80% as shown in Figure 4. Therefore, it is considered that the proposed risk assessment method is effective in predicting the ground subsidence.

Table 4. Weight factors from the AHP analysis

	F1	F2	F3	F4	F5	F6
	Pipe Type	Pipe Diameter	Burial Year	Removal System	Land Passage Number	Maintenance Control
Weight	0.1639	0.1270	0.2670	0.1352	0.1458	0.1653

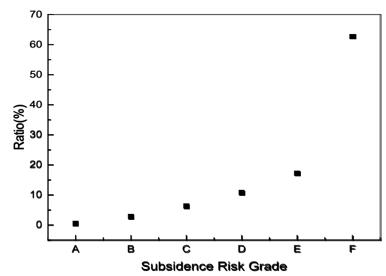

Fig. 4. Rate of subsidence risk grade near subsidence location

4 CONCLUSION

In this research, a method is proposed to evaluate the ground collapse risk with related to sewer pipeline characteristics. From the sewer GIS data, the installation year, pipe diameter, pipe type, drainage type etc. were extracted as factors affecting the occurrence of ground collapse. In addition to the extracted factors, surrounding road conditions and sewer maintenance history, which are factors related to ground collapse, were added. And then, AHP analysis was conducted based expert's survey result. As a result of the AHP analysis, the importance of influencing factor was indicated in the order of installation years → pipe type → maintenance history → surrounding road condition → drainage type → pipe diameter. Using AHP analysis result which provides the weights for the six Influencing factors, the sewer condition evaluation was carried out for a specific district of Seoul. In the condition evaluation, the proportion of F which is the worst condition was the highest. In fact, it is judged that the evaluation method presented by analyzing with E and F is effective as the result of the condition evaluation of the place where the ground collapse occurred. This analysis method can be used to analyze the factors affecting the ground subsidence and to establish a maintenance plan for the sewer pipeline.

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