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Original article

Derivation of risk factors according to accident cases related to subway structures

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Abstract

This study derives the risk-Influence factors for subway structures, the basis for the transition from the current subway disaster recovery-oriented maintenance system to a preemptive disaster management system, to reduce risk factors for existing subway structures. To apply reasonable risk assessment techniques, risk influence factors for subway underground structures using statistical information(spatial information) and risk influence factors according to frequency of accidents were selected to derive the risk factors. The significant risk factors were verified through ground subsidence (SI: Subsidence Impact)-based correlation analysis. This process confirmed that the subsidence of the ground was a risk influence factor for the subway structure. The main result of this study is that derive the risk factors to improve the risk factors of subway structures due to the rapid increase in disaster risk factors. The derived risk factors that were expected to affect the depression around subway stations and track structures did not show a noticeable correlation, but the cause of this may be that there is no physical connection between them, but on the other hand, the accumulated data may not accurately record the surrounding depression. Accordingly, in order to evaluate the risk of depression around the station and track, more intensive observation and data accumulation around the structure are required.

Keywords : Underground Space Information, Risk influence factors, Correlation Analysis, Subsidence Impact.

1. Introduction

The underground space is mainly filled with soil and water, making it difficult to observe visually. However, changes in the underground space are characterized by soil displacement. Due to diversification, complexity, and aging of urban railway underground structures and the surrounding ground, disaster risk factors (risk) that are difficult to grasp are rapidly increasing (The Ministry of Land, Infrastructure, and Transport 2019.07,31). However, the maintenance and safety management of structures in underground spaces is focused on rapid evacuation and recovery to prevent secondary damage. Additionally, many accidents occur due to the current maintenance and management of underground spaces and the growing risk factors. According to data from the Ministry of Land, Infrastructure and Transport, a total of 631 sinkholes occurred nationwide from 2014 to the first half of 2019. This includes areas of 1 ㎡ or more or when

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Table 1. Ground subsidence status from 2014–2018(Ministry of Environment,2019)

BY cause	total	2014	2015	2016	2017	2018
total	1,143	71	191	259	280	342
Sewage pipe damage	462	21	66	90	143	140
Water pipe damage	214	31	53	53	41	36
Excavation failure construction	61	6	13	19	13	10

The reason for the development of sinkholes in the last 10 years nationwide: water and sewage leak 52%, underground construction 27%.

ground subsidence occurs at a depth of 1m or more, except for simple potholes (road digs). 'Table 1' shows the current status of ground subsidence from 2014–2018. The table shows that the amount of ground subsidence has increased annually. Ground subsidence is a ground displacement phenomenon in which the ground gradually falls and reduces volume. Earthquakes or crustal fluctuations cause natural subsidence, and artificial subsidence is a change in the crust caused by pumping groundwater, underground construction, and construction of surrounding structures. In this study, the scope of underground structures and underground facilities is defined as subway structures and subway facilities through a review of existing literature. Also given the rapidly increase in risk factors that are difficult to understand due to the progress of diversification, complexity, and aging of underground structures and surrounding ground of urban railways, and the characteristics of underground structures. underground facilities, and surrounding ground, risk factors for each accident case related to the ground subsidence phenomenon for subway structures caused by factors are derived and compared with the deduction of risk factors using spatial information, and the effectiveness is verified through the correlation analysis of the finally derived risk items. Through this, we try to improve the risk items related to existing subway structures.

2. Existing Literature Review and Research Methods

2.1 Reviewing the existing literature

Existing literature : (Monitoring urban railway underground structures and surrounding ground risks (Korea Railroad Research Institute, 2017, 12), Comprehensive risk assessment and accident management technology development for extreme risk factors (Korea Atomic Energy Research Institute, January 19, 2015), etc..). According to related literature, such as the Safety Management Manual of the Korea Facilities Safety Management Corporation, all engineering facilities have potential unknown risks. Thus, existing literature and research reviews that show the severity and risk based on accident cases by type are evaluated. Further research is being conducted to minimize, predict, and prevent damage through monitoring studies using the Internet of Things. However, existing literature evaluates the severity and risk of train crashes, derails, fires, crossing accidents, and casualties in train operations. It does not evaluate accidents caused by subway structures. There is limited research or no research or related reports on risk screening and setting of urban railway underground structures. Therefore, this study's research progress and methods were established through a literature review, research cases, and reports related to ground subsidence. There are many causes of ground subsidence in urban areas where subways travel.

First, the most well-known ground subsidence phenomenon is a sinkhole. Sinkholes rarely occur except in some areas such as Samcheok. However, large-scale ground depots may occur due to large-scale underground structure construction. Second, a common phenomenon in urban areas is a ground trap caused by damage and deformation of aging sewage pipes. Artificial facilities such as water and sewage pipes may leak depending on the degree of aging and at poor joints (welding and coupling) when newly established.Leakage leads to soil loss (sand) and eventually causes ground deformation in the underground space, causing the surface to sink. Third, inappropriate excavation work causes ground subsidence or

deformation in underground spaces in two forms. Fourth, changes and fluctuations in the groundwater levels also result in damage. Several factors affect the groundwater level. Artificial acts, such as construction, sometimes lead to the excessive transfer of groundwater. In urban areas, high-rise buildings with deep underground spaces are built. They block the aquifer of groundwater or interfere with the natural flow of groundwater, resulting in changes in groundwater levels. This often causes displacement of the ground and appears as a ground subsidence phenomenon. Finally, heavy and torrential rains in the summer seasons lead to platform inflow and ground weakness. Platform flooding is accompanied by soil leakage, saturation of the surrounding ground due to soil moving with the outflow, causing ground softening, and temporarily saturated septo flows into cracks in platforms and tunnels, leading to ground subsidence. Moreover, in the event of heavy rain, an increase in positive pressure due to an increase in groundwater level may damage the foundation of the underground structure. Accordingly, the factors of ground subsidence directly damage the subway structure, and leakage due to the rupture of the water pipe can flow into the platform and tunnel. Variations in groundwater levels or outflow of soil due to inappropriate excavation may lead to an imbalance in loads in platforms and tunnel structures. Additionally, these factors cause cracks and corrosion of the structure. Changes in the environment around subway structures directly or indirectly cause damage to the underground structures and facilities. Based on related and previous studies, ground subsidence is attributed to leakage of water pipes, flooding due to torrential rains, displacement (depression) of the ground due to inappropriate excavation, and weakening of the ground due to fluctuations in groundwater. Thus, five major risk factors can be considered in addition to aging subway structures (platforms and tunnels). Therefore, this study investigates damage to subway structures due to rainfall flooding, excavation, pipeline leakage, groundwater level, and station aging. Thereby, risk factors for each accident case are derived, and risk factors according to risk influence factors using spatial information are compared and analyzed. Therefore, we intend to reduce the existing risk factors through correlation analysis.

2.2 Research method

This study intends to proceed with the research method as follows. Based on the categorization results of the ground subsidence main causes obtained through a review of existing literature, this study analyzes the status of spatial information built to determine the aging of subway structures and derives the risk factors for subway structures using statistical information. Accordingly, the aging of structures and the management of subway structure-related data are identified, and available subway structure spatial information related to aging are used as risk factors. Next, Through an accident case survey related to subway structures, we selected risk factors according to the cause of each accident case. They are compared with the selected risk factors related to subway structures using spatial information to derive statistical-risk factors, and their effectiveness is verified through correlation analysis. This process is intended to confirm that the derived risk factors are risk influence factors for the subway structure. ‘Fig. 1’ shows the schematization of research methods, that is, the method and sequence of research.

(1) Derivation of risk influence factors related to subway structures using spatial information by categorizing the main causes of ground subsidence obtained through a review of existing literature.

(2) Analysis of the current status of spatial information on the axis of equipment to determine the aging of subway structures and utilize spatial information.

(3) Calculation by dividing it into a platform (subway station) and subway tracks (tunnel) when deriving the risk factors.

(4) Risk selection stage: Investigate damage or accident cases on platforms (subway stations) and subway tracks (tunnels), identify accident causes, investigate related laws and safety standards, and select risk factors and related data (select risk factors through major accident factors based on underground structures accidents).

(5) Derivation of risk influence factors related to subway structures using spatial information and statistical information by categorizing the main causes of ground subsidence obtained through a review of existing literature.

(6) Derivation of risk influence factors through analysis of risk influence factors by accident case and risk influence factors using statistical information(spatial information).

(7) Correlation analysis is conducted to derive significant risk influence factors.

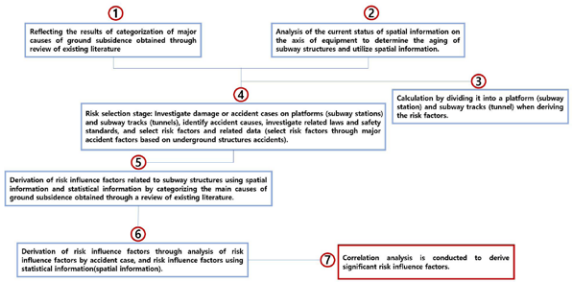

Fig. 1. Schematic study method

3. Main topic

3.1 Derivation of risk influence factors through analysis of accident case status

Accidents in underground spaces that cause ground subsidence can be classified into five types based on the analysis of existing and previous studies: flooding due to torrential rains, inappropriate large-scale excavation and leakage of water or sewage water pipes, fluctuations in groundwater, and aging of subways.

3.1.1 Analysis of invasive cases caused by torrential rain

'Table 2' shows the cause and location through an analysis of the inundation case. The backflow of sewage pipes to lowlands, excellent inflow of ventilation rooms that did not consider flooding of rivers, and flooding itself were the reasons for the accident. Flooding caused by torrential rain causes direct and indirect damage to subway structures. Seoul's subway platforms consist of 29 stations within 300m from the surrounding rivers, While 86 stations are located within 1 km. Thus, flood damage is expected in the case of torrential rain. Therefore, actions according to disaster prevention measures prepared to prevent flooding should be considered for torrential rain. However, secondary ground subsidence is not prevented. Thus, risk influence factors may consider the flooding area and flooding history after subsidence. Additionally, most flooding is caused by the reverse flow of nearby rivers because the platform area is low. Therefore, the validity of the design of the drainage plan is analyzed.

Table 2. Analysis of Cases of Ground Subsidence and Inflow into Platforms due to Water Flooding in Seoul

Cause	Place (station)	Date
torrential rain	Yeongdeungpo-gu Office, Dangsan	1984.9.1
	Sindap, Hongdae entrance, Gyodae, Gangnam, Euljiro 4-ga, Dongdaemun Stadium	1987.7.27
	Sindang, Dongdaemun	1996.7.6
	Yongdap, Sindap, Cheongnyangni, Seoul	1998.8.4
	Seolleung, Daechi, Dobongsan	1998.8.7
	Dobongsan	1999.8.2
	Cheongnyangni, Jongno 5-ga, Sindang, Gangnam Express Terminal	2001.7.5
	Yongsan	2002.8.7
	Jongno 3-ga	2003.8.24
	Line 1 : Cheongnyangni, Jongno 5-ga, etc. Line 2 : Seolleung, Sindang, etc. Line 3 : Daechi, Jongno 3-ga, etc. Line 7 : Taereung Entrance, Dobongsan, Gangnam Express Terminal, etc.	1998~2003
	Chungmuro	2017.7.11
	Magok	2020.8.13
	Gangnam	2011~2020

Table 3. Analysis of ground subsidence by excavating work

Year	Place (station)	Source
1995	The subway in Daegu	Inappropriate excavation work
2007	Gajwa, Seodaemun-gu, Seoul	Destruction of subway tracks caused by the collapse of the shaft wall
2012	The subway in Incheon	Ground displacement (depreciation) occurs during inappropriate excavation work
2014	Incheon Subway Line 2	Ground displacement of excavation work (deprecation)
2014	Sanjeong-dong, Mokpo-si, Jeollanam-do	Deterioration of the influence caused by digging
2014	Yeongjongdo Island, Sky City	The soil loss caused by improper excavation work
2014	Seokchon-dong, Songpa-gu	subway **failure** construction
2015	In front of Yongsan Station	Loss of soil due to excavation work

3.1.2 Case analysis of ground subsidence due to improper excavation work

Inappropriate excavation work causes ground displacement due to the deformation of the earth wall and the earth barrier wall. The ground displacement makes the surrounding ground fragile, causing the ground to sink. Additionally, in the excavation of Daesimdo Island, the deformation of the earth wall (soil barrier wall) will be greater, and the closer it is to the construction site, the greater the ground displacement. According to statistical data on the causes of ground subsidence during construction and the status of ground subsidence phenomena, the deformation of the ground due to improper excavation work accounts for 52%, and about 48% of the ground subsidence occurred near the existing structures. Statistical data on the causes and the current status of ground subsidence during construction. It indicates that 52% of ground deformation was due to inappropriate excavation work, and 48% of ground subsidence occurred around the existing structure. (chung, waterjournal 2015) This statistical data the possibility of the excavation work and existing underground structures affecting each other. Underground structures may be affected by surrounding construction, and most of them affect the leakage and deformation of temporary facilities. ‘Table 3’ shows an analysis of the location of accidents resulting from excavation work. Further analysis shows that inappropriate excavation, accompanied by soil leakage due to ground displacement and groundwater outflow, explosion due to groundwater degradation, and groundwater damage were the causes. Excavation has several risk influence factors that cause subsidence in the ground and have characteristics that affect the excavation length and depth. Therefore, the excavation depth and excavation distance are considered risk influence factors.

3.1.3 Leakage due to damage to water pipes

The water supply and sewage pipes are damaged by factors such as ground uplift and sinking due to the low depth of placement of the pipes. In winter, the water in the ground freezes, and the water in the lower parts rises due to capillary force, forming an ice lens. Then the ground subsides with changes in the season as it starts to melt in spring, called ground lifting. Approximately 20% of ground subsidence occurs in spring, and most of the pipes are destroyed by the ground uplifting, resulting in leakage. Additionally, damages may also occur during construction because of inappropriate excavation work. If the soil leaks due to leaking water and sewage pipes, the ground becomes fragile and causing secondary damage. ‘Table 4’ shows the location of ground subsidence accidents caused by the rupture and damage of water pipes. According to the analysis, there are various causes such as excavation work, ground subsidence, and sewage pipe leakage resulting in softening of the ground and secondary damage. Thus, the buried depth and ground condition (weakness) can also be considered as risk influence factors. There is also damage due to excavation work, but it is classified as caused by excavation work.

Table 4. Analysis of ground subsidence cases due to damage of water and sewage water pipelines

Year	Place (station)	Source
2012	Haeundae-gu, Busan	Damage to the sewer pipe
2014	Yeongdeungpo-gu, Seoul	Leakage caused by damage to sewage pipes
2014	Bangi-dong, Songpa-gu	Sewage pipe connection, pipe breakage, Sewage pipe breakage, water pipe leak
2014	Jamsil Sports Complex	Sewage box branch area damage
2016	Seokchon Station Intersection	Depression of 4m (sinkhole)

3.1.4 Softening of the ground due to changes in groundwater level

The decline in groundwater is a major cause of ground subsidence. Recent studies on changes in aquifer groundwater show that pumping groundwater blocked up and down by impermeable water reduces buoyancy to the upper ground supported by a saturated aquifer, causing ground subsidence. ‘Fig. 2’ compares and analyzes the current status of alluvial layers in Seoul and the ground subsidence phenomenon according to the subway route maps. The alluvial layers in Seoul are widely distributed along the Hangang River and its tributaries. The roads in Seoul are built along most of these rivers. As the subway has been planned underground below the road, half the routes are expected to be on the alluvial layer. Consequently, the subway structures are likely to suffer damage owing to fluctuations in groundwater levels. Considering the subsidence distribution of the ground, more than half of the ground depressions occurred along subway lines. Therefore, the distribution status of alluvial layers in Seoul and the distribution of ground depressions according to subway routes are sufficiently correlated.

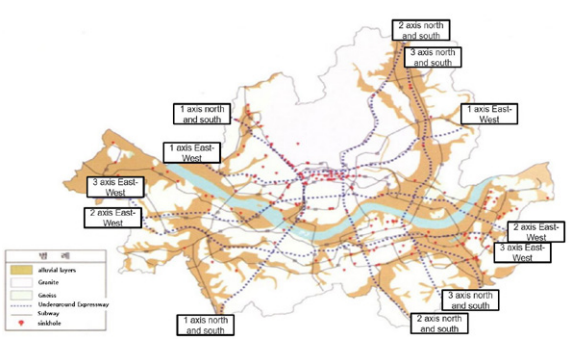

Fig. 2. Distribution chart of geological and ground subsidence in Seoul (data provided by Seoul)

The Seoul Metropolitan Government released data on changes in groundwater levels from 1996–2000, as shown in ‘Fig. 3’. This analysis shows that the groundwater level has decreased around the subway from 5 m to 15 m. Notably, an extreme drop in groundwater of more than 15 m occurred on the ground around the subway. The fact that it occurred around the subway designed using the drainage method above the alluvial layer is highly likely to cause large-scale damage to subway structures in the future.

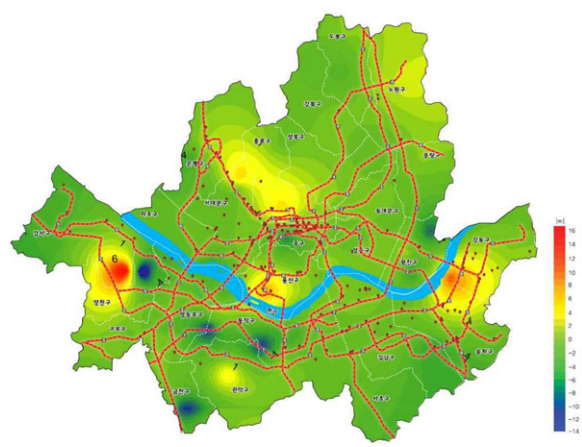

Fig. 3. Seoul distribution chart of underground water level changes from 1996–2000(data provided by the seoul metropolitan government)

‘Table 5’ shows an analysis of the location of the ground softening caused by the change in groundwater level. Further analysis shows that the ground softening was caused by the change in groundwater level. Typically, ground softening is caused by changes in the ground and the decline in groundwater. Such a decline in groundwater relaxes the soil. Here, the load from the upper levels increases, leading

Table 5. Analysis of damage to structures caused by the subsidence of the ground

Year	Place (station)	Source
2008	Cheongok-dong, Ulsan	Weakness caused by torrential rain
2013	Samsan-dong, Ulsan	The effect of sedimentation due to soft ground
2013	Hwamyeong-dong, Busan	Damage to sewage pipes due to the sinking of the soft ground
2014	Yeouido-dong, Yeongdeungpo-gu, Seoul	**Failed** road pavement work due to the soft ground sinking

to ground subsidence. Additionally, it damages connecting buried facilities. Therefore, groundwater usage and inflow quantity were selected as factors influencing the risk of subsidence in the ground due to changes in the groundwater level.

3.1.5 Ageing platform facilities

It has been 48 years since the subway opened in Korea. Approximately 70% of subway structures are over 20 years old. When subway-related structures are located underground, cracks and corrosion occur, surrounding groundwater or surface water may flow into the structure, causing ground subsidence. 'Fig. 4' shows the numerical analysis indicating that saturated granules can flow into the subway. 'Fig. 5' is an example of the aging and damage of subway structures. Due to the aging of subway-related facilities, concrete pillars, ceilings, exits, and stairs have slowly fallen off, and cracks were found in various places. Cracks in the structure jeopardize the safety of passengers. Cracks in the structure's outer wall introduce groundwater to create space in the ground and structures around, leading to sinking and damage. 'Fig. 6'shows the annual status of subway stations in Seoul as of 2020. Of the 291 stations, 103 are over 30 years old. Additionally, there are 20 stations with more than 40 years of history, and there is a growing

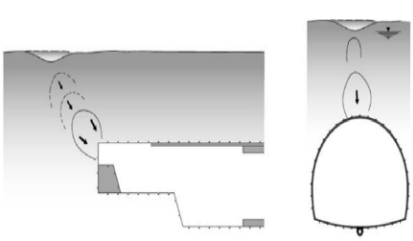

Fig. 4. Subsidence of saturated fine-grained soil into the tunnel (yooshin technical bulletin, vol 9, pp 120)

evaluation that it is structurally unsafe due to cracks and corrosion of concrete pillars and flooring materials that support the older structure. Risk influence factors due to the aging of subway structures include the common period and status rating.

Fig. 5. Aging and damage of subway

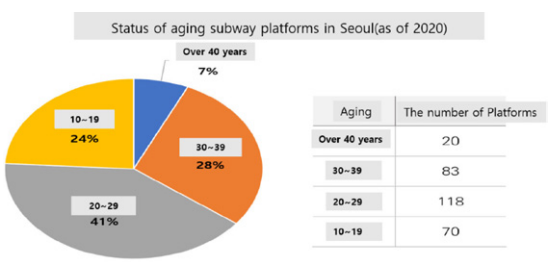

Fig. 6. Status of aging subway platforms in Seoul (data provided by Seoul)

3.1.6 Selection of risk factors by accident type

Based on the existing literature, previous research results, and accident case analysis of initial risk influence factors were derived (Public period, Design type drainage, Structure grade(structure condition), Excavation distance, Excavation depth, The flooded area, Ground condition (weakness), The collection inflow quantity(water volume), The amount of underground water used, Buried depth) as shown in 'Table 6' and were spatially classified into platforms and tunnels.

Table 6. Risk factors by accident type

Sortation	Source	Risk factors
Platform	Flooded by torrential rain	Flooding area, drainage
	Leakage due to rupture of the water pipe	Buried depth, ground condition (weakness)
	Excavation work, soil spill	Excavation depth, excavation distance
	Long-term depression of the soft ground	ground condition (weakness)
	The aging of subway platforms	Structure grade(structure condition)
	Groundwater level fluctuation, ground weakness	Groundwater usage and collection inflow quantity(water volume)
Tunnel	Long-term depression of the soft ground	Ground condition (weakness)
	Leakage due to rupture of the water /sewage pipe	Buried depth, inflow quantity
	The aging of subway tracks and tunnel-related facilities	Public period
etc	The surrounding phenomenon	The subsidence of the ground, the phenomenon of potholes (depression of the country depression)

Table 7. Risk influence factors using risk analysis

Mark	Explanation	Mark	Explanation
SC	Structure grade(structure condition)	GW	Ground condition (weakness)
DS	Excavation distance	SL	Public period(service life)
BD	Buried depth	WU	Underground water usage(water usage)
WV	The collection inflow quantity(well volume)	DP	Excavation depth
DT	design type drainage(drainage tyupe)	FA	Flooded area

4. Correlation analysis

After identifying the correlation between the selected risk factors according to the depression-impact degree of the subway structure, the final risk influence factors (risk factors) were determined.

4.1 Data analysis of ground subsidence (depression)

Data on influencing factors were statistically analyzed to evaluate the risk of ground depression around urban railway stations and track structures. The data used for the analysis are shown in 'Table 7'.

Securing the quality of the data is also important for ensuring the reliability of the analysis results. However, the total amount of data must be sufficient to gain trust in the analysis results. 'Fig. 7'. shows the amount of data used in the analysis by risk factors. At least 42 of a maximum of 527 data points were used for the analysis. However, there were less than 50 data points on structure grade (SC: Structure Condition), design type drainage (DT: Drainage Type), excavation depth (DP), and excavation distance (DS), and the number was not sufficient for analysis. Therefore, compared to the correlation analysis through the subsidence impact degree of risk influence factors, the remaining six variables were estimated to be more than 200, which would be somewhat meaningful.

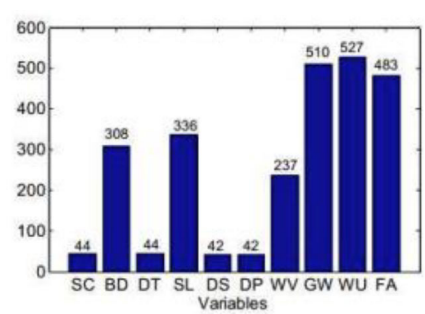

Fig. 7. Data count distribution

'Figs. 8 and 9' shows a probability mass function representing the probability distribution of the amount of data for each risk influence factor. Considering the probability distribution of the structure grade(SC), the case where the grade does not exist has a probability of 0.92, and the probability of grade B is 0.067. The remaining values were less than 0.01. In terms of the number, of the 44, there are 3, 39, and 2 structures with grades A, B, and C, respectively. Therefore, it was confirmed that a meaningful probability distribution could not be obtained. The maximum value of the probability distribution of the BD (Buried Depth) is 49.5 m, mainly distributed in the range of 10 m to 30 m, with an average of 19.2 m. Although the minimum value is somewhat skewed to the left from the average, it is acceptable for statistical analysis as it shows a relatively even distribution. The design type drainage (DT) was divided into 1 for construction in a drainage state and 2 for construction in a non-drain state, and the ratio of drainage to non-drainage was 0.34:0.66. However, there were only 44 data points on drainage, very small for statistical processing. The public period (SL: Service Life) is up to 50 years of data distribution, and except for year 25, it tends to be similar to the normal distribution. The average value of the useful years was calculated as 23.7 years. It was confirmed that the number of data was 336, making it easy to analyze. Although the excavation distance(DS) is characterized by relatively uniform distribution, up to 25 m or less, there were only 42 data points, insufficient to provide statistical meaning. The excavation depth(DP) distribution shows an even distribution similar to the excavation distance(DS), but the amount of data is very small. The probability distribution of the collection inflow quantity (WV: Well Volume) is very high, at less than 100//day of 0.536 and less than 500//day of 0.82. As the inflow is observed only in platform structures, there are approximately half the number of tracks. Ground condition (weakness, GW) is the result of giving investigation according to the relative weakness with the most fragile ground as 1.0, and the most solid ground as 8.0. The probability sum of the weak ground 1 and 2 is 0.7. In other words, 70% of platform can be seen as having a weak ground. The solid ground (weakness degree 8.0) also had a probability of 0.26. The average value of softness was 3.34, which was weak. Although there are 510 data points on the ground condition (weakness), it is characterized by an extreme distribution in two forms: weak and solid. The underground water usage (WU: Water Usage) has 527 data points, which have sufficient values and can have statistical significance. The minimum value was approximately 100 $m^3/d/km^2$, and the average value was 140.0$m^3/d/km^2$. The FA (Flooded Area) was the highest in less than 100ha, and the larger the area, the lower the probability. The probability of a 400ha or less flooded area was 0.96, and the average flooded area was 93.2ha.

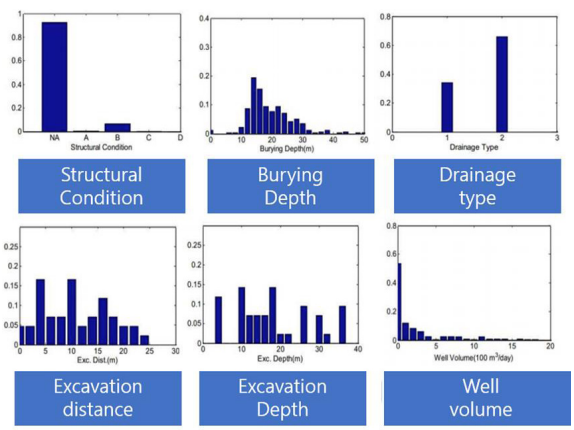

Fig. 8. Probability distribution (1)

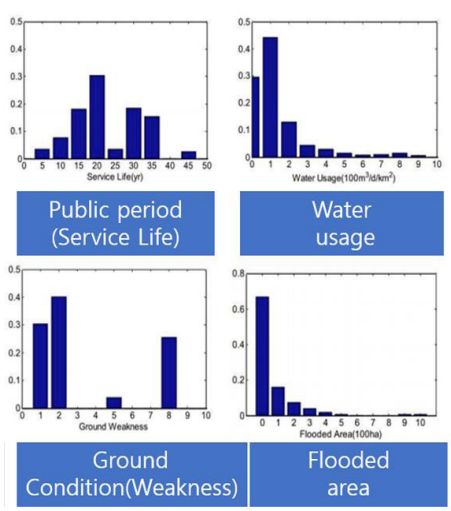

Fig. 9. Probability distribution (2)

4.2 Correlation analysis of ground subsidence (depression)

It can be seen that the larger the size of the subsidence, the greater the impact on the structural stability of the ground subsidence occurs near the railroad tracks and stations. Therefore, the degree of influence of the depression is inversely proportional to the occurrence distance and proportional to the size of the depression. Based on this, the depression effect (Subsidence Impact) was defined as one index(Eq.(1)).

$$SI = -\sqrt[n]{\frac{S_0^n + S_r^n}{d}}$$

S_0 : The scale of depression(m^3)
S_r : The size of depression recovery(m^3)
d : Depression occurrence distance(m)
Eq. (1). Subsidence Impact

Here, S_0 is the scale of occurred depression (m^3), S_r is the size of the depression recovery (m^3), **d** is the distance(**m**) from platform(station) or track to depression. The smaller the index (n), the greater the influence of the distance, and the larger the index (n), the smaller the influence of the distance. The probability mass function when the index (n) is used as 1 is shown in 'Fig. 10'. As shown in the 'Fig. 10', the probability that SI is less than 1.0 is 0.88, which is very high. This is because the distance of occurrence of depression becomes relatively more important than the size of the depression. 'Fig. 11' shows the index at 5 to increase the importance of the depression size. The probability that the SI is less than 1.0 decreases to 0.445, and at the same time, the probability of the area above 1.0 increases. This is because the importance of the depression scale was increased by increasing the index (n). In this way, the probability distribution function is affected by the index (n), and 'Fig. 12' shows the probability that SI is less than 1.0 when the index is changed. It can be seen that the index (n) decreases rapidly up to 5 and then gradually changes. Therefore, in this task, the index (n) used in the equation was fixed to 5 and then analyzed.

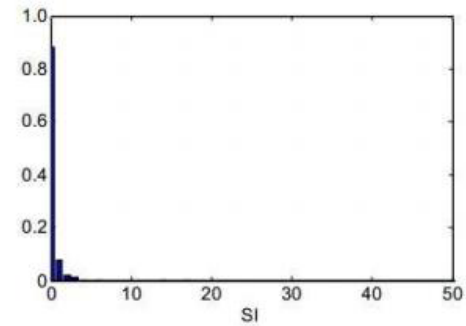

Fig. 10. Probability distribution according to subsidence impact (n=1)

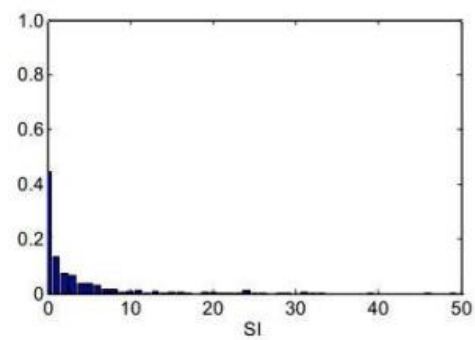

Fig. 11. Probability distribution according to subsidence impact (n=5)

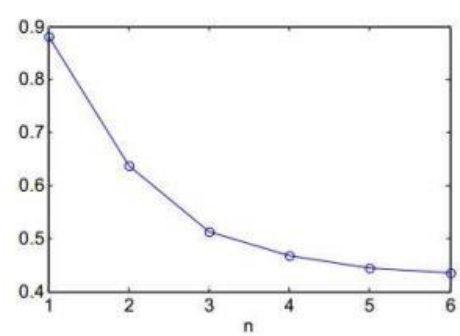

Fig. 12. Degree of probability variance according to the subsidence influence index

'fig. 13' shows that the Structural Grade(SC) has a correlation coefficient of 0.107. However, as the corresponding data is less than 50, it is excluded from the correlation result. The BD shows various distributions, but as the subsidence influence is concentrated at less than 40, and the correlation coefficient is very low at 0.055, it cannot be

considered correlated. The number of relevant data analyzing the correlation of drainage type (DT) is very small with 44. The small correlation itself is also a problem. According to the presence or absence of drainage, the subsidence impact (depression impact) is rather negative. Therefore, it is judged that it is difficult to discuss the correlation. 'fig. 14' shows that the public period (service life, SL) has a correlation coefficient of 0.099. The excavation distance (DS) was 0.263, indicating a correlation. However, the evaluation result of the excavation depth (DP) was very low at 0.031.

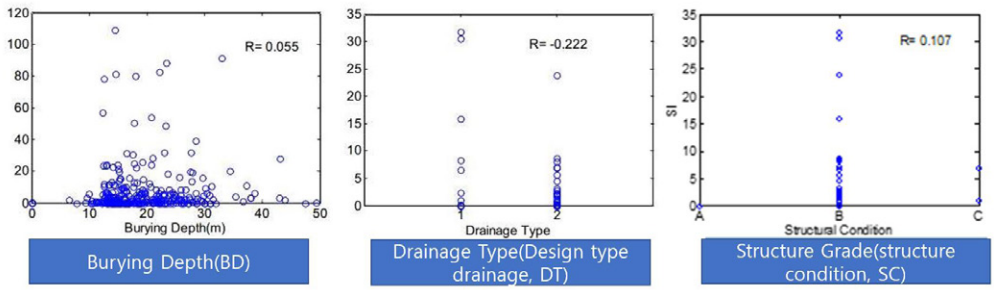

Fig. 13. Results of ground subsidence correlation by Risk-influence factors(y=SI) (1)

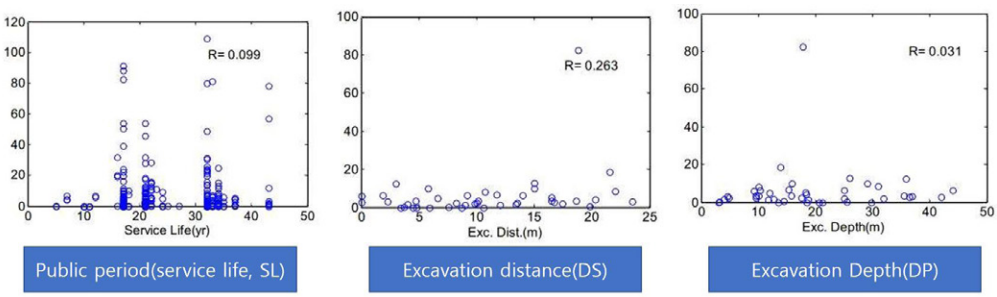

Fig. 14. Results of ground subsidence correlation by Risk-influence factors(y=SI) (2)

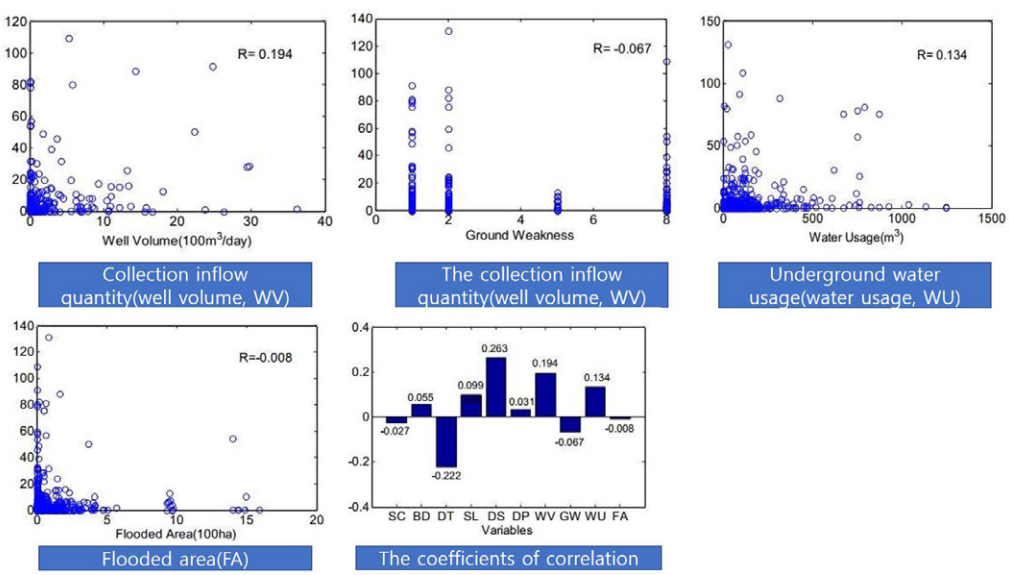

Fig. 15. Results of ground subsidence correlation by Risk-influence factors(y=SI) (3)

'Fig. 15' shows that the correlation coefficients for the collection inflow quantity(well volume, WV), ground condition (weakness, GW), underground water usage(WU), and FA were also 0.194, -0.067, 0.134, and -0.008, respectively. It is reasonable to show a negative correlation because the vulnerability increases as the ground conditions (weakness) and FA decrease.

5. Conclusion

The risk factors were derived as a result of investigating cases of subsidence and accidents related to subway structures and analyzing them by type. The risk influence factors were selected for the following: public period(SL), inflow quantity(WV), ground condition (GW), and FA, excavation distance (DS), underground water usage (WU).

The coefficients of correlation analysis between the nine risk influence factors (Fig. 15) with the subsidence impact (depression) showed no noticeable correlation between the influencing factors expected to affect the depression around subway stations and track structures. The maximum value based on the absolute value was 0.263 at the excavation depth, and all the rest showed lower values. Analysis of this showed no noticeable correlation between the influencing factors that were expected to affect the depression around subway stations and track structures according to the data available at this stage. The reason for this may be that there is no physical connection between them. However, there is a possibility that the accumulated data may not accurately record the situation of the surrounding depression. Accordingly, it is necessary to examine the flooded area, seen in 'Fig. 16', and the flooded area and depression area of 25 district in Seoul. This is an analysis of the correlation by aggregating the flooded area and the number of depressions caused by heavy rain during 2008–2015 by district offices. The total number of depressions was 484, and the flooded area was 4910 ha. After aggregating them by district offices, the correlation coefficient was relatively high at 0.711 (decision coefficient 0.506) when analyzed after summing them up by a total of 25 district offices. In other words, the flooding area and the number of depressions were correlated with adjacent areas. However, when comparing 'Fig. 15 - flooded area(FA)' with the subway platform (station) and the collapse of the railroad area, a clear correlation cannot be found. Although the depression occurs due to the flooding, it is highly likely that it will spread to the flooded area, but it is always possible that the depression occurs in the platform (station) and in the direction of the track. the fact that it is not. Therefore, more intensive observation and data accumulation around the structure are required to evaluate the risk of depression around the platform (station) and track.

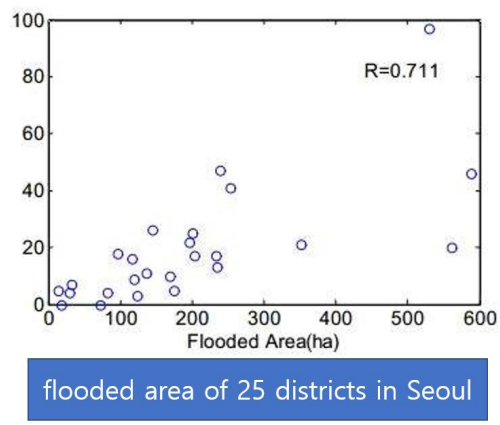

Fig. 16. Flooded area and depression area of 25 districts in seoul

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References

Korea Institute of Construction Technology, ICTWAY (2019.07,31), *Planning to develop technologies to support automation and exploration site utilization of integrated underground maps*, Research report, Ministry of Land, Infrastructure and Transport

Lee, S.J., Park, Y.K., Lee, J.W., Kim, B.K., Chae, D.H., and Kim, S.i. (2017.09), *Development of Monitoring Technology for Railway Structures and Urban Ground*,

KOREAN SOCIETY OF CIVIL ENGINEER, 65(9), pp. 28-33

Lee, I.H.(2017,12), *Development of IOT-based Urban Underground Utility Monitoring and Management System*, Research report, Electronics and Telecommunications Research Institute

Construction Safety Department of Construction Policy Bureau (2019.07), *The 1st Basic Plan for Underground Safety Management (2020~2024),*

Kim, E.H., Choi, H.S., and Kim, T.H. (2009), *The Intelligent Information Service Model of Urban Spatial Information for u-UIS - Focused on Urban Ground and Underground Facilities,* Journal of Korea Spatial Information System Society, v.11 no.1, pp.189 - 194

Facility Safety Technology Corporation (1996), *Detailed guidelines for tunnel safety inspection and precision safety diagnosis*, Ministry of Construction and Transportation, pp.1 - 66

Kim, H.S., Chun, S.H., and Chung, C.K., (2010.10), *Development of integrated system for management and application of geo-information and underground structures/facilities informationbased on GIS*, KOREAN SOCIETY OF CIVIL ENGINEERS, pp. 370-373

Kim, Y.S., (2011.12), *The Study of Risk Matrix Development for Urban Metro EMU*, Journal of the Korean Society of Safety, v.26, no.6 pp.111 - 117

Korea Evaluation Institute of Construction and Transportation Technology (2011), *Establishment of Risk Analysis and Assessment System for Railway Accidents and Hazards*, Research report (TRKO201800000817), Ministry of Land, Transport and Maritime Affairs, korea

Kang, I.J., Pusan National University (2018.05), *Building 3D information of ground and underground using GIS and BIM*, Research report, Ministry of Science and ICT

Kim, C.S., Pukyong National University (2007.06), *Development of Man-made Disaster Prevention Technology;The Safety Management System in the Underground Space*, Research report

Pyeon, M.W., Konkuk University (2020.07), *Quantitative performance analysis of urban railway underground structures using spatial information*, Research report, Korea Railroad Research Institute

yooshin technical bulletin, vol 9, pp 120

Jo, H.I (2019), *engdaily*, http://www.engdaily.com/news/articleView.html?idxno=10473, (last date accessed: 20 August 2021) Ministry of Environment.