Development of subsurface cavity potential map for prevention of road cave-in

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ABSTRACT

Road cave-in accidents occur frequently in many parts of the world recently. Unique and state-of-the art technologies for prevention of cave-in have been innovated through various experiences over 30 years in Japan. Survey technology of subsurface cavity improved with precision and speed, repair material for cavities and research on cavity/cave-in has progressed. Regarding evaluation of cavity/cave-in, each data of subsurface cavity was used for prediction of risk to cave-in itself, but this study is the first attempt to evaluate the regional area based on cavity information. The map indicating subsurface cavity/cave-in potential, named “Subsurface Cavity/Cave-in Potential Map” was developed based on collaborative studies of government-academia-industry.

Keywords: subsurface cavity; road cave-in; regional characteristics; factor analysis; evaluation of potential

1 CURRENT APPROACHES TO PREVENT OF ROAD CAVE-IN IN JAPAN

The massive cave-in accident in November 2016 caused by underground construction at HAKATA attracted global attention. The interests of people around the world were both its scale and the rapid adaptation of recovery. And social awareness changed to reconfirm the importance of keeping safety of road. After the huge accident, Japanese national government started to take action for keeping safety of utilizing underground spaces from technical viewpoint. As a result, a policy report which treats geotechnical information sharing was submitted in 2017.

On the other hand, since the 1990s, several Japanese public administrations began subsurface cavity surveys utilizing ground-penetrating radar technology. The trigger of starting surveys was a social issue known as the “cave-in syndrome” that a fact of multiple road cave-ins in Tokyo in 1988. From then on, the surveys have been conducted regularly all over Japan that focus on cavities due to damage of aged buried infrastructures, influenced by high-density underground development, and fluctuation of groundwater level. In recent years, emergency surveys were carried out after large earthquakes in order to ensure disaster recovery activities (Fig.1). Thus, Japanese high quality initiatives and know-how to prevent cave-in: survey technology, new repair material, and research on mechanism of subsurface cavity have evolved through those successive activities. In addition, these Japanese technologies supported the initiation of measures for cave-in in South Korea (Fig.1).

Regarding efforts to reduce factors of cavities, rebuilding and rehabilitation of sewages can be highlighted. Tokyo metropolitan reported the reduction of cave-ins due to measures for aged sewerage in 2016. As for road administration, the direction of cave-in prevention measures is under discussion in terms of two issues that Japan faces today: maintenance and management for enormous aging underground infrastructure, and reduction of accidents by cave-in against intensifying natural disaster.

Fig. 1. Photo of urgent investigation after Kumamoto earthquake in 2017 and photo of cavity survey in South Korea in 2014.

2 THE PURPOSE OF DEVELOPMENT OF THE POTENTIAL MAP

The purpose of development of the subsurface cavity/cave-in potential map is to understand the regional condition. For keeping road function against cave-ins, it is necessary to consider the road network around the cavities. The regional assessment of the potential of the cavity/cave-in and the map showing it give some benefits. It takes appropriate measures not only for regular situation but also for emergency situation such as large-scale natural disasters. In addition, these approaches will support discussion at other local governments that starting new measures for cave-in as experienced cases.

3 A STUDY FOR POTENTIAL EVALUATION

3.1 Understand the tendency of cavity occurrence

Table 1 shows the occurrence frequency of cavities by road administrators and characteristics based on a report (Koike et al. 2017). The high frequency values of the Tokyo metropolitan, ordinance-designated city, and the 23 wards of Tokyo suggest that developed urban areas hold factors such as aged buried infrastructures and high-density underground development.

Table 1. The occurrence frequency of cavities and road characteristics by road administrators.

Road administration	Number of cavities per road length	Utilization of roadside and underground
National and prefectures	0.59 /km	Environs Small to many
Tokyo and ordinance designated city	2.06 /km	Urban High density, subway
23 wards of Tokyo	2.09 /km	Urban High density, subway
Others	1.37 /km	Residential Small to many

3.2 Causes of cavities

Road cave-in occurs suddenly with collapse and broken pavement. However it is caused by a small ground phenomenon. Some air voids form a cavity by expanding upward initially, after the cavity achieves subbase, it expands horizontally. Then the strength of pavement exceeds its limit, a cave-in ensues finally. The factors forming cavities can be considered as washout of soil particles through a broken utility, consolidation settlement of soil particles in the subgrade, loosen soil around underground structure, and fluctuation of groundwater level. In many cases, some contributing factors influence each other forming cavities. Fig. 2 shows photos as actual examples of cavity and factor of cave-in.

A cavity below pavement | Sewer pipe junction and groundwater under a cavity | Damaged sewer pipe which caused a cavity

Fig. 2. Photos at detail investigations of cavity and a broken sewer pipe by aging which caused a cave-in.

3.3 Classification of factors of cavities and definition of potential

Tendency of cavity occurrences is evaluated using "number of cavities" and length of investigations. When evaluating the risk of cave-in, it is necessary to consider "scale of cavity" and "possibility of cavity expansion". In addition, there is a valuable finding from the previous survey and research that formation/ expansion of cavity depend on factors. In this study, factors of cavities are classified into two types of "environmental factor" and "influential factor". When a channel of sediment outflow is formed by an influential factor in an environmental factor that supports causing cavities, the cavity expands quickly. The definition of potential for subsurface cavity/cave-in is explained by the degree of contribution of the factors in this study. The factors of cavity are summarized using the two categories as shown in Table 2.

Table 2. Summary of factors and potential of cavity.

2-1. Underground utility.

Environmental factor	Influential factor	Factors to expand
Number and Congestion	Defect and failure; backfill, connection of pipeline, breakage by other construction etc.	Washing out from breakage point
Aging	Breakage	Washing out from breakage point
Repair history	Degradation of repair material	Washing out from breakage point
Backfill	-	Fluidity of backfill

2-2. Underground structure.

Environmental factor	Influential factor	Factors to expand
Formation of water fountain	Fluctuation of underground water	-
Looseness of soil around structure	Looseness of soil around structure	-
Degradation of remaining temporary structure	rot	-

2-3. Revetment structure.

Environmental factor	Influential factor	Factors to expand
Aging	Breakage of revetment, Defect of joint	tide

2-4. Commons.

Ground water	Fluctuation of underground water
Soil	Particle size, permeability
Ground form	Road structure, filling
Natural disaster	Heavy rain, large-scale earthquake, liquefaction

4 DEVELOPMENT OF CAVITY POTENTIAL MAP IN FUKUOKA CITY

4.1 Overview of Fukuoka city and its efforts to prevent road cave-in

Fukuoka city is the center of administration, economy and transportation of the Kyushu region in Japan. Its public sewerage works began in the 1950s and it became an ordinance-designated city in 1972. Regarding natural disaster, heavy rain often attacks there and a large-scale earthquake damaged northern coastal areas in 2005. The efforts to prevent road cave-ins, subsurface cavity survey and repairment have been conducted in cooperation since 1994 and a collaborative study with the UNIV. of Tokyo started in 2015.

4.2 Analysis for factors of cavity in Fukuoka city

In the past 5 years of 2012 - 2016, 630 cavities were confirmed by investigation of 497.9 km length in the roads managed by Fukuoka city. From these results, the occurrence frequency of cavity equals 1.30 /km, which is lower than the value of ordinance-designated cities as 2.06 /km, shown in Table 1.

According to repair records, there is a finding that the factors of cavities can be classified roughly into two types of “soil washout” and “others”. The classification into this two types was by overlying and analyzing with data of cavities and sewer system ledger of Fukuoka city. Regional analysis were carried out using the classified 630 subsurface cavities. As the results of regional analysis between the environmental factors and the occurrence frequency of the cavity, several highly factors in Fukuoka city were correlated obtained; "soil washout - ageing, material of sewer pipes", "others - reclaimed area, construction method of subway, and liquefied area in the past". Some of the results are shown in figures 3-5 (Hotta 2018).

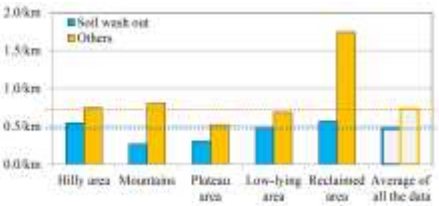

Fig. 3. Occurrence frequency of cavity by ground form.

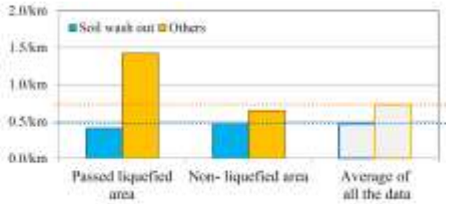

Fig. 4. Occurrence frequency of cavity by liquefied area in the past.

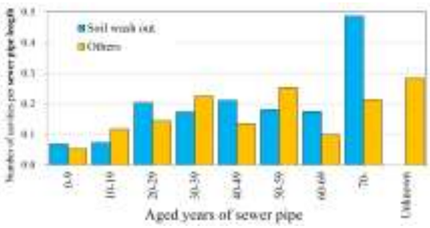

Fig. 5. Occurrence frequency of cavity by length of sewer pipe classification into aged years.

4.3 Examination of cavity potential evaluation - trial of weighting by AHP method

In examining of cavity potential evaluation value, weighting was attempted by both of a quantitative method and a qualitative method (Hotta 2018). An example of the results by qualitative method is as described below. AHP method was selected as a subjective analysis methods. Because, it has an advantage for reflecting the intuitive understanding of the analysis result in the calculation easily, although it is not possible to reflect the interaction between factors. Regarding the standard of weighting value, it was set using the ratio between the maximum- minimum values of the occurrence frequency of cavity. After several calculations by AHP method, the potential value of cavity was estimated using occurrence frequency of cavity.

4.4 Prototype of cavity potential map of Fukuoka city by AHP method

Figure 6 shows the results of examination of the cavity potential evaluation and maps of Fukuoka city (Hotta 2018).

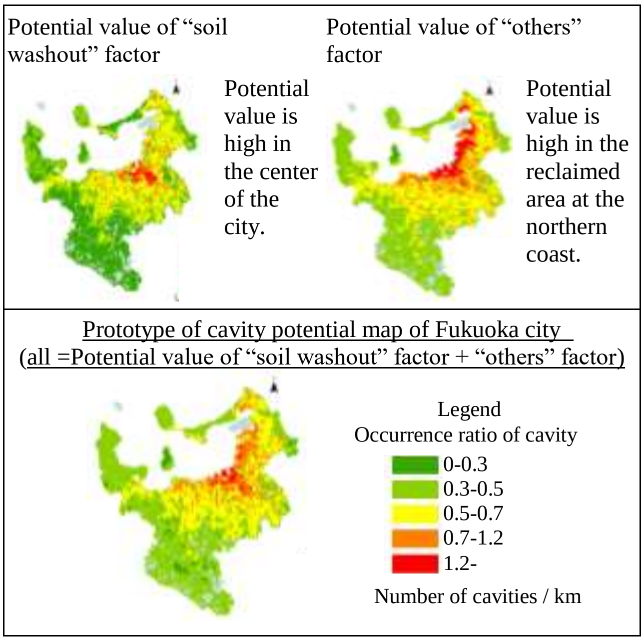

Fig. 6. Cavity potential map of Fukuoka city by AHP method.

5 DEVELOPMENT OF CAVE-IN POTENTIAL MAP IN FUJISAWA CITY

5.1 Background and outline of the development of cave-in potential map in Fujisawa city

A collaboration among Fujisawa city and the Univ. of Tokyo and GEO SEARCH started to develop effective solutions for prevention of road cave-in accidents in Fujisawa city in 2017. Fujisawa city is located in the central part of Kanagawa Prefecture adjoining western Tokyo. The south area faces the Pacific Ocean and the alluvial lowlands of the Shonan dunes lies. The intensive developments of infrastructure such as roads and sewers were during 1950’s to 1970’s. In recent years, deteriorate of infrastructures by the aging was obviously, and the handlings for them become a serious issue (Hatakeyama et al. 2018). This study focuses on possibility of expansion of cavities, not only occurrence of cavity, the data of more than 430 cave-in at whole city and the data of trial monitoring surveys on 10 roads were analyzed. And valuable data managed by Fujisawa city that sewage, groundwater, geological borings and so on were also used regional overlying and analyzing. In addition, detail surveys of cavity occurrence were conducted to find out their factors. Based on knowledge and findings obtained from these collaborative activities, four environmental factors: the oldness of sewage, the number of utilities, the level of groundwater, and the permeability of soils were selected as the regional potential factors. Figure 7 shows the figures of a cavity occurrence by the detailed investigations and Figure 8 shows a sewer map as one of environmental factors of cavity in Fujisawa city. In addition, the effects and the evaluation techniques of cave-in potential were set by discussion that evaluated by belonging factors to each divided grids and threshold level of four factors.

Fig. 7. Figures of a cavity occurrence situation by the detailed investigations in Fujisawa city.

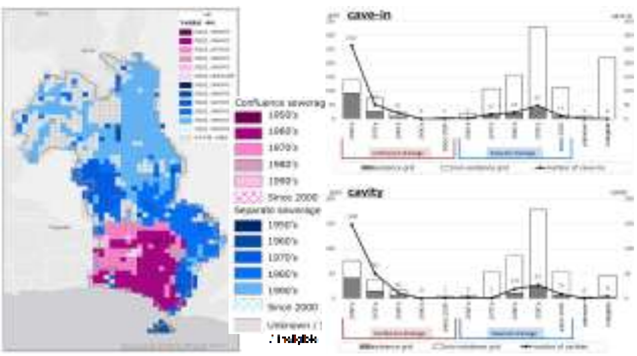

Fig. 8. A classified sewer by drainage method and oldness and analysis of occurrence frequency of cave-in and cavity.

5.2 Prototype Cave-in potential map of Fujisawa city

After making sure for appropriateness by sensitivity analysis of four potential factors in each, a knowledge that cavities often occur under overlapped multiple factors was reflected on this evaluation as a new attempt. Figure 9 shows the prototype of cave-in potential map of Fujisawa city that evaluated based on the degree of overlap of multiple factors.

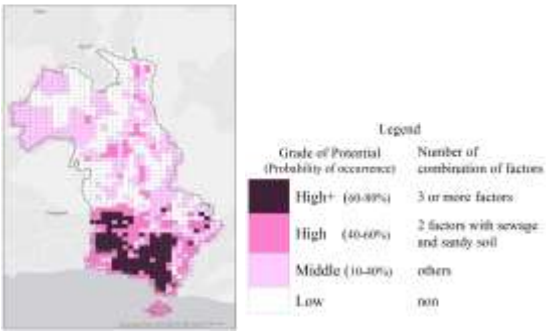

Fig. 9. Prototype of cave-in potential map of Fujisawa city.

6 CONCLUSION

These first attempts to evaluate the area by the cavity information was able to produce results with the output named Potential Map. This was achieved by reliable cavity survey data, various regional information concerned cavity/cave-in, the findings from activities, and previous knowledge about cavity. The evaluation of Fukuoka city using cavity survey data and repair records gave the results by classifying cavities roughly with sewer management data. In case of Fujisawa city, various data such as cavity survey data, actual cave-in information, the results of monitoring surveys, detailed investigations of cavity, sewer information were used. Thus, those gave realistic to the evaluations. Preventing road cave-in is key to keeping road traffic functions. And it is also a disaster-resistant system. These collaborative studies are most leading, advancing, and practical cases in the world. In the future, we would like to make effort to develop evaluation even more effective.

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