On-site Monitoring Surveys and Investigations of Subsurface Cavity for Effective Road Cave-in Prevention

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ABSTRACT: Road cave-ins have frequently been occurring in many parts of the world. Subsurface cavity survey is a key measure to prevent road cave-ins. A public-academia-private collaborative team discussed the mechanism of cavity formation and expansion. The present research aims to monitor the behaviour of cavities on 10 roads where more than 80 cavities are under observation by monitoring surveys. The target roads are located mainly on the sandy ground of Fujisawa City, Japan, near the Pacific Ocean. A radar exploration mounted car that can detect subsurface cavities in three dimensions was used for this survey. After 2 years surveying every 6 months, it was confirmed that 7 cavities were expanded, and 32 cavities were newly formed. 15 investigations were conducted to find out the cause of cavities by open-cutting. All the causes and conditions of the cavity were identified; in some sites, sandy ground, shallow groundwater, and sewer defects seemed to trigger the occurrence of mostly cavities.

Keywords: road cave-in, cavity, sandy ground, radar exploration, sewer pipe

1. Measures against road cave-in in Japan

Preventing road cave-in is key to keeping road traffic functions. Since the 1990s, several Japanese public administrations began subsurface cavity surveys utilising ground-penetrating radar technology. The trigger of starting studies 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 focuses on cavities due to damage of aged buried infrastructures, influenced by high-density underground development, and fluctuation of groundwater level [1]. In recent years, emergency surveys have been carried out after large earthquakes to ensure disaster recovery activities. Cavity surveys are now being conducted in countries other than Japan (Fig. 1). Such unique and state-of-the-art technologies for the prevention of cave-in have been innovated through various experiences over 30 years. Notably, the survey technology of subsurface cavities was the most essential by the improvement in accuracy and speed. It leads to a reduction in road maintenance costs as early detection.

Besides, based on field investigations, survey data analysis, and cave-in mechanisms have been discussing [2]. Moreover, the development of repair material for cavities has progressed. On the other hand of administrative view, the Road Law was revised to add the duty of maintenance for exclusive users of under road buried objects to prevent cave-in in 2018. Moreover, 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 old sewerage in 2016[3].

Figure 1. Photo of an urgent investigation after Kumamoto earthquake in 2017 and a picture of the cavity survey in Thailand in 2016.

2. About collaborative study

2.1. About Fujisawa City

Fujisawa City is located in the central part of Kanagawa Prefecture, adjoining western Tokyo. In the northern part of the city, the Sagami Plateau, which was formed by the activity of the Fuji volcanic zone about 400,000 years ago, extends into gentle hills that rise to an elevation of 40 to 50 meters. The south area faces the Pacific Ocean, and the alluvial lowlands of the Shonan dunes lie (Fig. 2). The city has been developed as recreation, tourism, and residential area more than 100 years ago. Currently, it has developed as a commercial center in the Shonan area and has a population of 400,000. The intensive developments of infrastructure such as roads and sewers were during the1950s to 1970s. In recent years, the deterioration of infrastructures by ageing was apparent, and the handlings for them become a serious issue.

Figure 2. Photo of the topography of Shonan area [4].

2.2. Issue of Fujisawa City about the cave-in

In the two years before this study, 98 major roads in Fujisawa City surveyed. The length of the survey was 300km, and a large number of 202 cavity signals were confirmed. The cavity signals were evaluated for the risk of the cave-in, depending on the necessity of repair. Fujisawa City has established a countermeasure policy using the evaluation, and the city has begun to repair the cavities to ensure safe road traffic functions. On the other hand, some issues were organised—first, measures for the future in the southern area where the cavities were extraordinarily dense and overcrowded. The next is to understand the behaviour of the cavity with a low risk of a cave-in. Finally, it is the future policymaking in the whole city based on these issues. These issues were also urgent because they had an impact on securing road traffic functions and creating a disaster-resistant city. Therefore, in this study, the mechanism of the expansion process leading to the formation of cavities in Fujisawa City was clarified through more than 10 on-site investigations.

2.3. Organisation

The public-academia-private collaborative team was organised with Fujisawa City, The University of Tokyo, and GEO SEARCH (Fig.3). The member from Fujisawa City belonged to the section of Road and River Department and Sewage Department. The team aimed to develop a method for the city to efficiently prevent road cave-ins in the future as a way to realise Fujisawa City's theme of "building a safe and secure living."

Figure 3. The organisation of the collaborative study.

The team conducted analysis and discussion based on field investigations for two years from April 2017 to March 2019. As a result, they have created a result that is the basis of the action policy for preventing cave-ins. Through the organised and analysed the knowledge gained from their activities, they have developed the method for future prediction and evaluation of the occurrence of the cavity and created a result that is the basis of the action policy for preventing cave-ins.

3. Monitoring survey for cavity behaviour

3.1. Subsurface cavity survey in a regular way

The subsurface cavity survey is conducted using vehicles equipped with underground radar equipment. In Japan, surveys are regularly conducted approximately every 3rd to 5th years. The target roads and survey frequency are determined by the tendency of the cavity and the importance of roads. Fig.4 shows the cavity exploration vehicle developed by GEO SEARCH. The specification of the survey is as below:

- Maximum speed: 80km/h (under legal speed)
- Depth:1.5m
- Width:2.5m / one pass
- Exploration Ability: the cavity bigger than width 50cm x length 50cm x thickness 10cm

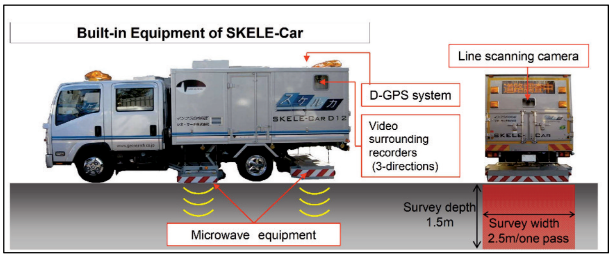


Figure 4. The mounted device of the cavity exploration vehicle.

High accuracy of the cavity survey is necessary to prevent a cave-in because it is challenging to find cavities in the invisible and diverse underground. Thus, technology is needed to analyze not only exploration equipment but also the radar cavity signals. As of June 2019, GEO SEARCH, who held high accuracy of cavity analysis as 88%, identified 79,763 cavities in a total length of 207,456 km survey with their evolution of continuous exploration technology development.

3.2. Monitoring survey

In the collaborative study, monitoring surveys were carried out on 10 roads every 6 months, in a shorter period than usual in order to pursue when and how much new cavities were generated and expanded.

Regarding target roads, based on the survey results before the study, the monitoring roads were 10 roads, including 4 roads with high cavity occurrences and 6 comparative roads. The road length was 15.5km, and the survey length was 25.8km. At the beginning of the monitoring survey, there were 20 repaired cavities and 55 unrepaired cavities left under their roads. Every 6 months in April and October in 2017-2018, a total of 4 times monitoring surveys were conducted. Results of monitoring surveys.

3.3. Results of the monitoring surveys

After two years of monitoring surveys, 32 new cavities occurred in addition to the 55 remaining cavities. Moreover, 7 expanded cavities were confirmed. Most of those cavities were identified at the sand ground with sewage pipes ageing in the southern area of the city. 4 of the new cavities fast rose until direct under the pavement, and the other 28 new cavities occurred in the roadbed. 3 of the 7 expanded cavities moved to shallower and the other 4 cavities expanded horizontally (Fig. 5). The behaviour of both new and expanded cavities did not gradually increase during the four surveys every 6 months but moved at a certain moment. the actual behaviour of the cavities at a certain timing was grasped. This behaviour was mainly observed in sandy ground, but there were also cases of loam layers. Through monitoring surveys at intervals that were not normal, the actual behaviour of such cavities was confirmed.

Regarding repairs, 20 cavities have been repaired before monitoring surveys, and 15 cavities were repaired within 2 years, and a total of 35 cavities are being repaired. In many cases, repaired cavities reappear, so the around repaired cavities were carefully investigated and analysed. Thus, a total of 107 cavities' and around ground behaviour was monitored in the surveys. Table 1. shows the summary of monitoring surveys of the cavity.

Table 1. Summary of cavities behaved in monitoring surveys.

New occurred	32 cavities
Fast rise until direct under the pavement	4 cavities
Occurred in the road bed	28 cavities
Expanded	7 cavities
Expanded to upward	3 cavities
Expanded horizontally	4 cavities
Repaired	15 cavities
Before monitoring surveys	
Remained	55 cavities
Repaired	20 cavities
A total of monitoring cavities (32+55+20)	107 cavities

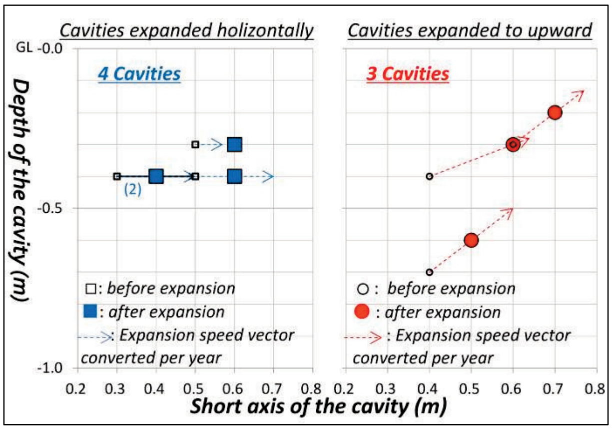


Figure 5. Behaviour of the cavities in monitoring surveys.

3.3.1. Frequently occurring of cavity: CASE A

Fig. 6 shows an example of a high-frequency cavity occurrence road section (hereinafter called "CASE A") using a road surface image taken by the line scanning camera of the cavity exploration vehicle. 4 cavities were confirmed within 25m. Fig.7 shows the size of a cavity; length, width, thickness, and depth.

Table 2 shows the data of each cavity, specifications, survey history, and other information.

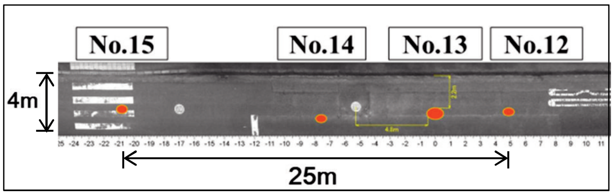


Figure 6. Cavity location map of CASE A taken by the cavity exploration vehicle (red points are cavity).

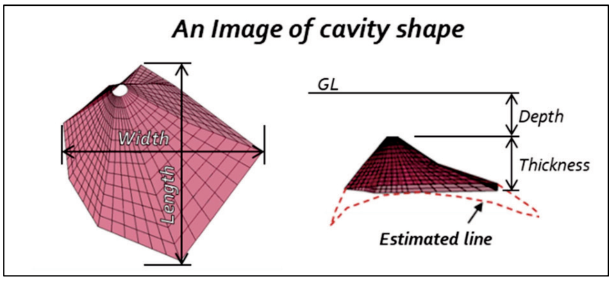


Figure 7. Specifications of Cavity.

Table 2. Survey result data of CASE A

No.	Survey Type*	Cavity		Result
		Depth	Length x width	
No.12	Previous	0.7m	0.4m x 0.4m	Default value
	1st	Same as above		No change
	2nd	Same as above		No change
	Repair	With the detail investigation, Dec. 2017		
No.13	Previous	0.3m	1.0m x 0.6m	Default value
	1st	Same as above		No change
	2nd	0.2m	1.0m x 0.6m	Expand upward
	Repair	With the detail investigation, Dec. 2017		
No.14	Previous	0.4m	0.6m x 0.3m	Default value
	1st	Same as above		No change
	2nd	Same as above		No change
	3rd	Same as above		No change
	4th	Same as above		No change
	Separately, monitoring investigations were conducted inside the cavity.			
No.15	Previous	0.5m	0.7m x 0.5m	Default value
	1st	Same as above		No change
	2nd	Same as above		No change
	3rd	Same as above		No change
	4th	Same as above		No change

*Note: about survey type;
"Previous" is Oct. 2016, before monitoring surveys.
"1st" is Apr.2017. "2nd" is Oct. 2017. "3rd" is Apr. 2018. "4th" is Oct. 2018.

3.3.2. Data of expanded cavity: No.13

As shown in Table 2, the No.13 cavity expanded upward in just 6 months. This phenomenon was confirmed by the change in the cavity signal in GPR as shown in Fig 8. This cavity was confirmed to expand upward but not horizontally.

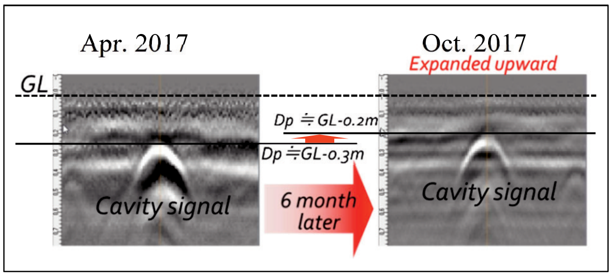


Figure 8. Cavity signal of GPR data of expanded cavity: No.15

3.3.3. Monitoring investigations of inside the cavity: No.14

At the cavity of No.14, the monitoring survey of the inside condition of the cavity was conducted 4 times in 2 years. In the investigations, the scoping survey with a borehole camera was inserted into the cavity to measure the cavity thickness as shown in Fig. 9 and observe the internal condition as shown in Fig. 10. As shown in the below figures, the No. 14 cavity was formed within the subgrade of the sandy soil layer, and the upper part of the cavity was an arch.

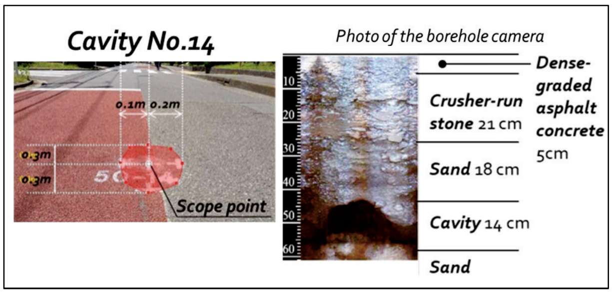


Figure 9. Location photo and photo of the borehole camera of the cavity of No.14.

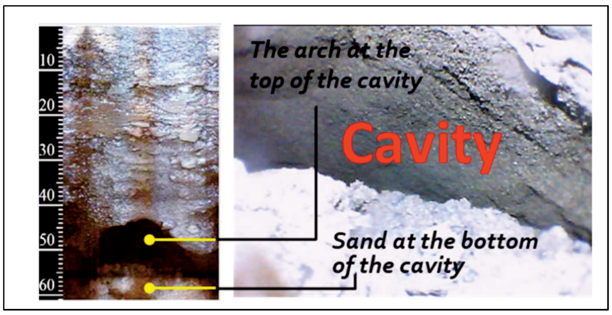


Figure 10. Photo of the internal condition of the cavity of No.14.

After scoping surveys, the portable cone penetration tests were conducted every time to understand the looseness under the cavity. Fig.11 shows the results of 4 portable cone penetration tests, but all showed the same trend, and no significant changes were observed. Table 3 shows the thickness of the cavity and the thickness of the loosen layer below the cavity in the four surveys.

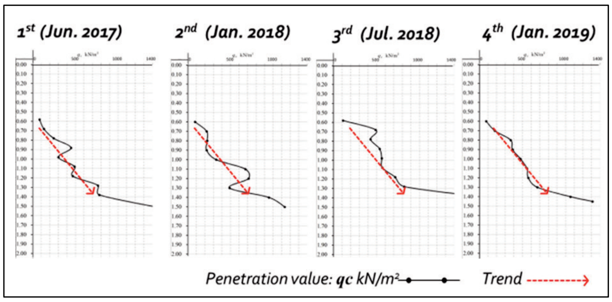


Figure 11. Results of 4 times the portable cone penetration tests at below the No.14 cavity.

Table 3. Survey result of cavity No.14 of CASE A.

Survey time	Cavity thickness	Loose layer thickness below cavity	Result
1st Jun.2017	14cm	0.7 m	Default value
2nd Jan.2018	Same as above	1.0 m	No change
3rd Jul.2018	Same as above	0.8 m	No change
4th Jan.2019	Same as above	0.8 m	No change

4. Detail investigation of cavity

Since this is the collaborative study, the detail investigations of the cause of the cavity were realised. During the study period, 15 cavities were repaired. Among these, 11 cavities' factor and around the ground were investigated and sampled, and soil tests were conducted. Usually, the time for road regulation is limited, so if the cause is not found even if the soil under the cavity is dug to a certain extent, it is often backfilled without taking any action. The following are 4 cases report of survey results showing typical cavity occurrence.

4.1. Case 1: Cavity occurred in sand layer with high groundwater level

This case is the No.13 cavity described in the previous chapter. The cavity was confirmed of expanded upwards in a short period of 6 months by the monitoring survey, so repaired as an emergency response, and a detailed investigation was conducted at the same time.

Fig. 12 shows the appearance of the cavity in the crushed stone layer just under asphalt and the size measured on-site (70cm x 70cm).

Figure 12. Photos of No.13 cavity formation.

When the sandy ground under the cavity was dug down, groundwater appeared at GL-1.45m, and the joint of sewerage (HP, φ800) appeared at GL-1.64m in the groundwater. This sewer pipe was built in 1969, but there was no damage on the outside. Therefore, as a result of an internal camera survey of sewer pipe, intrusion water was found on both shoulders (Fig. 13).

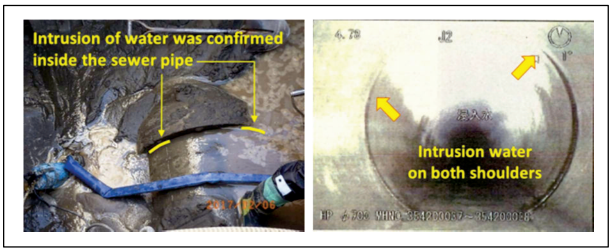


Figure 13. The sewer pipe joint in groundwater (left) and intrusion water confirmed in the sewer pipe (right).

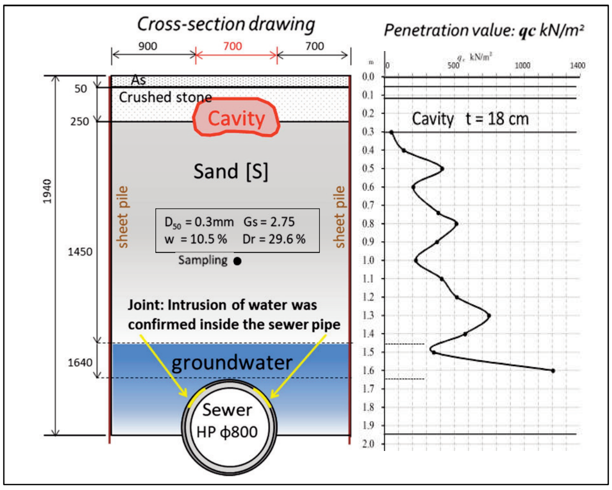


Figure 14. Cross-section drawing showing the condition of the No.13 cavity occurrence and the penetration value of below the cavity.

Fig.14 shows the condition of the No.13 cavity occurrence by the cross-section drawing and the penetration value of the cavity. Below the cavity was a loose sand layer to the groundwater surface. A result of soil test of sample at a depth of 1m was that D50 = 0.3mm, Gs = 2.75, water content = 10.5%, relative density = 29.6%.

With these actual conditions, it was presumed that the soil around the sewer pipe flowed out with groundwater, and then this cavity formed. It was a small gap in the joint of the pipe that the soil flowed. After this investigation, the cavity was restored with the shoulder of the sewer pipe was cured with mortar.

4.2. Case 2: Cavity caused by a defection of the sewage pipe joint

The size of this cavity is; depth = 0.2m, thickness = 43cm, length = 1.3m, and width = 0.9m. This case is also a cavity that was urgently repaired in sandy ground. In the 1st monitoring survey, this new, large, shallow cavity was explored, so it was urgently repaired based on the judgment that the risk of cave-in was high, and a detailed investigation was conducted at the same time. This investigation and repair took two days. Fig. 15 shows the location of the cavity before open-cut and the previously repaired cavity that close to the sewer pipe. Besides, the cavity was observed to be in the sand with gravel after being open cut.

Figure 15. The location of the cavity and the cavity in the sand with gravel.

Under the cavity and sand with gravel ground, the joint of sewerage (HP, φ1650) appeared at GL-2.43m in the parched and loose sand. This sewer pipe was built in 1966. When examining the joint part, it was confirmed that there was a slight lack of mortar as the finger could insert a little (Fig. 16).

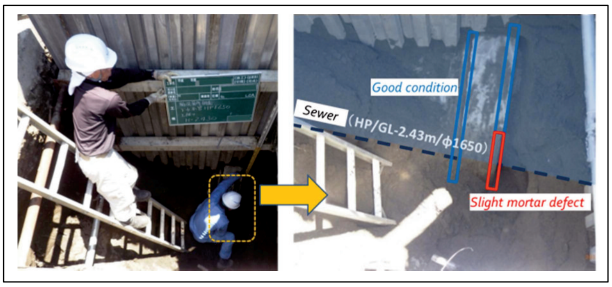


Figure 16. The joint of sewer pipe under the cavity.

Fig.17 shows the condition of the cavity occurrence by the cross-section drawing and the penetration value of the cavity. Below the cavity, there was a layer of sand with gravel and loose sand layer. As a result of soil test of sample at a depth of 2m, D50 = 0.3mm, Gs = 2.72, water content = 7.5%, relative density = 6.3 %.

The penetration value and very small relative density values showed that the sand layer under the cavity was very loose. That is the characteristic of this cavity occurrence. From these investigation results, it became clear that a tiny gap makes the loosening of the sand layer of 1m or more, and a cavity formed in a short period above it.

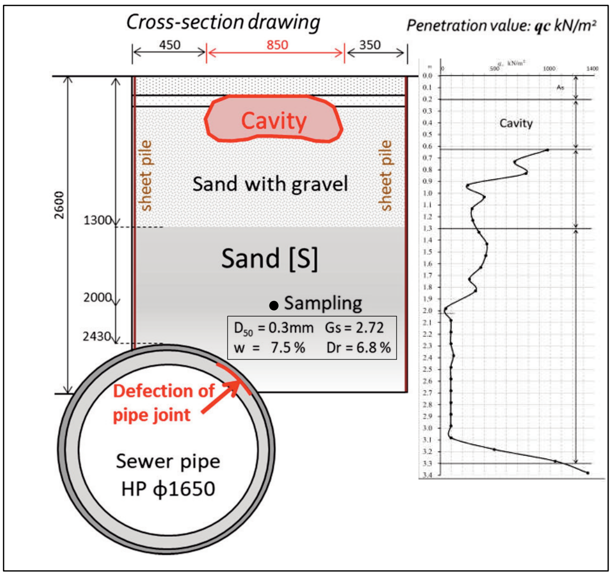


Figure 17. Cross-section drawing showing the condition of the cavity occurrence and the penetration value of below the cavity.

4.3. Case 3: Cavity caused by soil flowing out from utilities damaged by excavation work in a sand layer

As revealed by excavation, this cavity was thick and expanded upwards in a short period and occurred at the place where the buried utilities were congested. The size of this cavity is; depth = 0.15m, thickness = 50cm, length = 0.3m, and width = 0.4m. This case is also a cavity that was urgently repaired in sandy ground. In the 2nd monitoring survey, this new, shallow cavity was explored, so it was urgently repaired, and a detailed investigation was conducted at the same time. Fig. 18 shows the location of the cavity before excavation, that close to the attached sewer pipe.

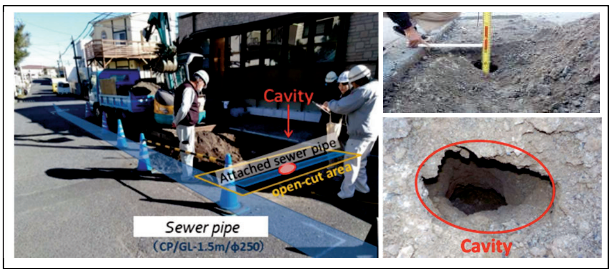


Figure 18. The location of the cavity and cavity formation.

As shown in Fig. 19, just 20cm below the cavity, there was a ceramic sewer attachment pipe partly replaced with a PV pipe and a water pipe crossing under there. In addition, there was a small defection at its connection point of the pipes. From these facts, it is considered that the cavity formed by backfilling soil flowing out from the defection point. Moreover, it is thought that the construction work of a crossing water pipe under the attachment pipe broke the attachment pipe and replaced it.

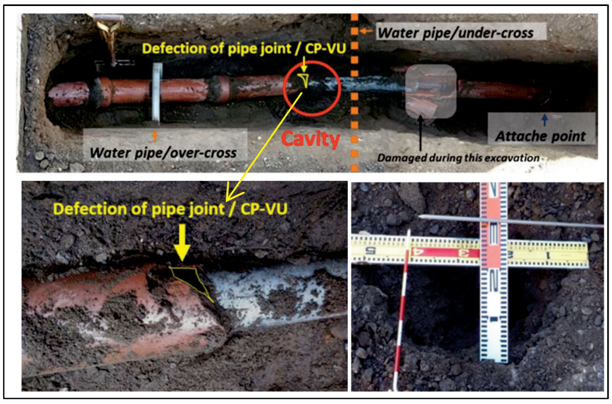


Figure 19. Picture of the defection of the pipe joint and the cavity.

Fig.20 shows the condition of the cavity occurrence by the cross-section drawing and the penetration value of the cavity. Below the cavity, there was the replaced pipe in the sand layer. The result of soil test of sample at a depth of 0.7 m was that D50 = 0.4mm, Gs = 2.70, water content = 8.2%, relative density = 7.0 %.

The penetration value and very small relative density values showed that below the cavity was very loose. Besides, the penetration resistance was large, and there was no looseness below the defection point. From these investigation results, it became clear that even a small gap created artificially could cause a cavity, and a cavity is formed in a short period above it.

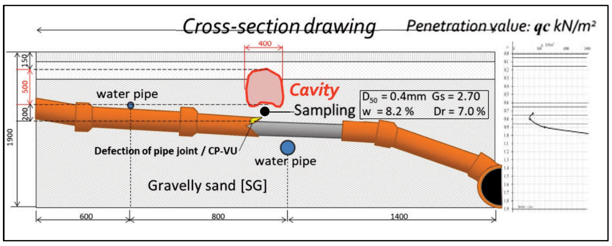


Figure 20. Cross-section drawing showing the condition of the cavity occurrence and the penetration value of below the cavity.

4.4. Case 4: Cavity caused by soil flowing out from utilities damaged by excavation work in the loam layer ground

This cavity that found at 2nd monitoring survey as a newly occurred cavity expanded the fastest in the monitoring survey. Its expansion rate was converted to 1.35 m3 / year. The average of other behavioural cavities is 0.1 m3 / year, which indicates that the cavity has expanded very fast in a short time.

However, the condition of this cavity was different from the cavities reported in this paper. This cavity occurred in the area of the loam layer ground, and the shape was characteristic. This case was also a cavity that was urgently repaired, and a detailed investigation was conducted at the same time. The following is a report of the actual conditions revealed by the detail investigation.

Fig. 21 shows the location, the shape of the cavity as long in the longitudinal direction, and the cavity was very shallow. Besides, there were some utilities around the cavity. The size of this cavity is; depth = 0.2m, thickness = 50-60cm, length = 3.2m, and width = 0.4m.

Figure 21. The location of the cavity.

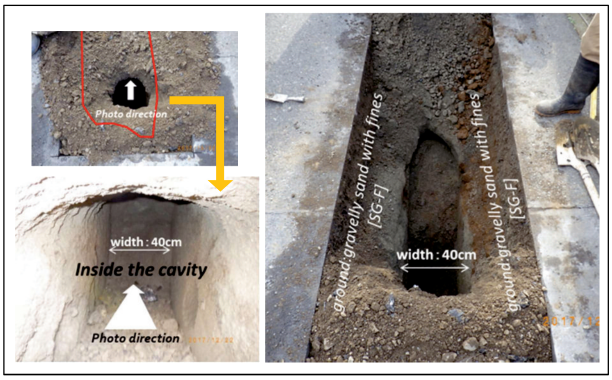


Figure 22. Picture showing the cavity formed in the ground non-flowability soil as of natural ground.

Fig. 22 shows that this cavity was formed in the ground non-flow-ability soil as of natural ground. The two photos on the left are the internal conditions of the cavity taken with the camera in the wellhead before excavating. There was “a space like an artificial waterway.” The cross-sectional shape of the cavity was an artificial square. Inside the cavity, the self-standing sidewall extended straight in the longitudinal direction of the road. The right side photo shows that the sidewall of the cavity did not collapse at all even, and it remained independent. When digging the loosen sand under the cavity, a water pipe and a sewer pipe were confirmed at a depth of 1.1-1.3m. Regarding the sand around the cavity, it was different from the natural ground as sidewall, and it .would be considered that the backfilling when those pipes were constructed.

Fig.23 shows the condition of the cavity occurrence by the cross-section drawing, longitudinal-section drawing, and the penetration value of the cavity. The cavity was formed like an artificial waterway because only backfill material on the pipes flowed without erosion of the ground—besides, the penetration resistance value in-creased in proportion to the depth.

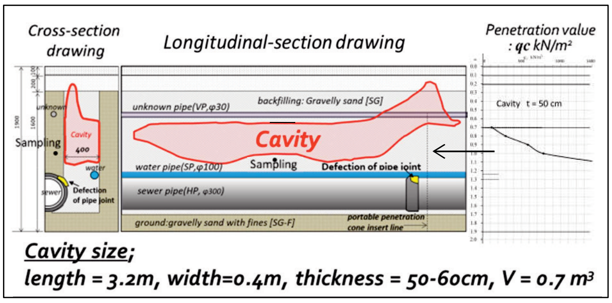


Figure 23. Cross-section drawing showing the condition of the cavity occurrence and the penetration value of below the cavity.

The condition around the cavity is as follows the self-standing ground is an artificial shape of 40cm width, the backfill material is sand, and the damaged part of the sewer pipe joint that caused the void protruded slightly from the natural ground. The joint was seemed to be damaged by excavation work. For repair of there, the damaged part was covered with mortar, but the pipeline was not replaced. The capped mortar lost adhesive strength due to ageing and the environmental condition, and the gap occurred. This gap was getting more extensive; it became a path for around sand to flow out; thus, the cavity formed.

Fig.24 shows the detail condition of the deteriorated mortar. There was floating the cover mortar. When it was peeled off, a broken sewer pipe appeared.

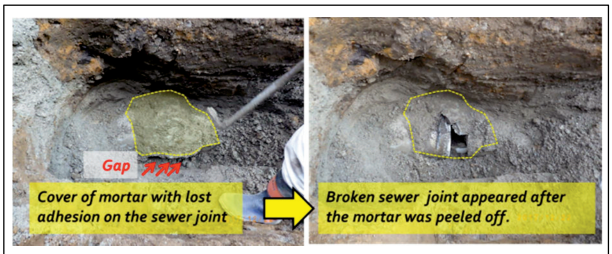
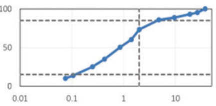
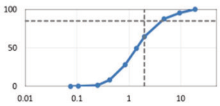
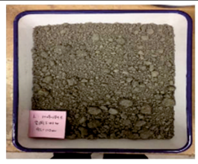


Figure 24. Photo of the cause of the cavity as the gap by mortar deterioration covering sewer pipe joint breakage.

Table 4. shows the condition of the natural ground soil as beside the cavity and the condition of sand under the cavity. A comparison showed that the situation was different. The natural ground contained fine fraction, and the water content was a high value. On the other hand, the sand under the cavity had a high relative density.

Table 4. Comparison of soil conditions between ground and backfill.

	Natural ground soil / beside of the cavity	Backfilling soil / under the cavity
Note	Standing upright beside the cavity, High water content	High relative density, low water content compared to natural ground
Soil classification	Gravelly sand with fines [SG-F]	Gravelly sand [SG]
Color	Brown	Grey
Soil particle density	2.67	2.80
water content	77.6 %	12.9 %
Relative density	63.1 %	94.6 %
Grain size:	D50 = 0.8 mm 	D50 = 1.4 mm 
Photo		

Weather information during this rapidly expanding period had records of heavy rains in excess of 60 mm/hr. It is unclear whether this rain caused the sewage pipe to become full or the groundwater level to be high. Still, the high moisture content of the natural ground indicates that the ground around the cavity was immersed in water. It is presumed that the velocity of the backfill sand flowing out along with water in trenches formed by the excavation of natural ground with a low roughness coefficient is higher than the speed in sandy ground.

From these investigation results, it became clear that even if it is not the sandy ground where cavities are easy to generate and expand, large cavities may be formed at a rapid rate.

5. Conclusions

The public-academia-private collaborative team that organised with Fujisawa City, The University of Tokyo, and GEO SEARCH worked on the practical study for the realisation of effective countermeasures against a cave-in for 2 years. The study was based on various investigations in the field. As an effort, cavity monitoring surveyed on the roads using ground-penetrating radar vehicles. Through the surveys at short intervals, such as once every 6 months, the actual behaviour of cavities was confirmed. The average number of cavities per kilometer of roads managed by local governments in Japan is 2.06 number/km [5]. Regarding this, 7 out of 10 routes had a frequency higher than the average. The frequency of occurrence of this study was; 0 number/km for the minimum value, 14.3 number/km for the maximum value, and 5.2 number/km on average. The routes were mainly in the area of sewage pipes that have dilapidated in sandy lands. It was an environment where cavities tended to occur. This monitoring-challenge provided an explicit confirmation of the reality and trends of on-site cavities. As a result of the investigation and analysis of 107 cavity behaviour, it was confirmed that 32 new cavities occurred, and 7 cavities behaved in two years. In the measurement accuracy of the GPR of 10cm unit, it was found that these cavities did not grow gradually over two years, but rather spread horizontally or both horizontally and vertically for a limited period. On the other hand, Hotta[6] extracted the enlarged cavity from 20 years of cavity survey data of one city, calculated the speed of expanding as 0.055 m3 / year. On the other hand, in this case, it was understood that the actual condition was expanded by 0.01 to 0.79m3 in six months. The average expansion value per year converted to 0.13m3 / year, which is larger than the value of 0.055m3 / year. This value indicates that the area was an environment in which cavities were easy to form. Detail behaviour of cavity was clarified for the first time, such as what kind of cavities occurs and expands at what timing. The reality investigations of the cause of the cavity were also realised. Cavities' factor and around the ground were investigated and sampled, and soil tests were conducted. In this paper, four cases are reported showing typical cavity occurrence. In Case 1 and Case 2, it was presumed that the cavity was formed by the washout of sand from small gaps formed by ageing in the joint of the sewer pipe under sandy ground. In Case 3, it became clear that even a small gap created artificially could cause a cavity, and a cavity is formed in a short period above it. In Case 4, it became clear that even if it is not the sandy ground where cavities are easy to generate/expand, large cavities may be formed at a rapid rate. The cavities in the sandy ground in Cases 1 to 3 are considered to be the same as the phenomena in experiments in small soil chambers [7]. In the experiment, a cavity was formed by soil flowing out from the tight slit under the ground using silica sand. Regarding the ground around the cavity, Nakamura et al [8] reported the results of trend analysis using the measured values of the looseness under the cavity of 1937 actual roads. However, the paper did not deal with detailed individual facts. This study was the first time that soil tests and measurements of loosening below the cavity were conducted under the situations that the outflow destination of the cavities identified in this study. It was observed that the depth of flow-out matched with the thickness of looseness below the cavity. Clear information was reported that the depth of the sediment discharge matched with the thickness of the looseness below the cavity.

The cavity is invisible; thus, understanding the actual condition of cavities is essential for effective countermeasures. In the collaborative study, Road Cave-in Potential MAP[9] that shows a regional factor of the cave-ins was developed using the various and actual conditions. We hope to continue to sublimate on-site information into knowledge.

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