A STUDY ON EXPANSION AND COLLAPSE OF SUBSURFACE CAVITIES FOR RISK EVALUATION OF ROAD CAVE-INS

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ABSTRACT: Cave-ins or sinkholes often occur in urban cities and the risk of cave-in occurrence seems to increase due to the aging of underground structure and intensified climate such as strong typhoons and heavy rains. Therefore the mechanism of cave-in formation should be understood to maintain roads efficiently. In this study, a series of model tests simulating the process of cave-in formation was conducted and it was found that there seems to be linear relationship between width and depth of a cavity immediately before collapse. Also, MLIT's reports on cavity/cave-in incidents were analyzed statistically and the same tendency was confirmed.

Key Words: *Cave-in, Model tests, Case analysis*

INTRODUCTION

The process of cave-in formation was investigated in this study. It is generally considered that cave-ins are often initiated by cavities in the ground. According to the MLIT (Ministry of Land, Infrastructure, Transport and Tourism) report, every year 3,000 to 4,000 cave-in incidents were generated due to damaged underground pipes in Japan. Among them damaged sewer pipes are considered as one of the major reasons for cavity formation. Typical process of cave-in formation is as follows (Kuwano et al, 2010).

1. An old sewer pipe is damaged and gets a hole
2. Soil around the damaged part is drained and a cavity is formed
3. The generated cavity moves up to the surface, sometimes with expansion
4. Surface layer becomes insufficient to support its weight and traffic load, and eventually collapses

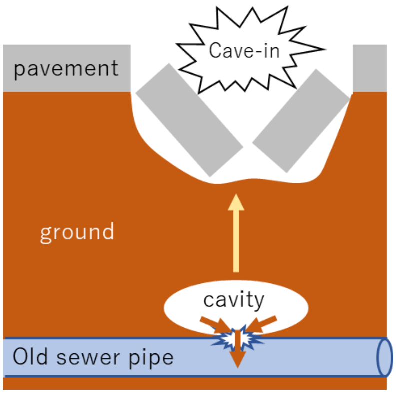

Figure 1. Formation of cave-ins

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Thanks to the developed techniques, shallow cavities are now detectable using high accuracy probing vehicle as shown in **Figure 2**.

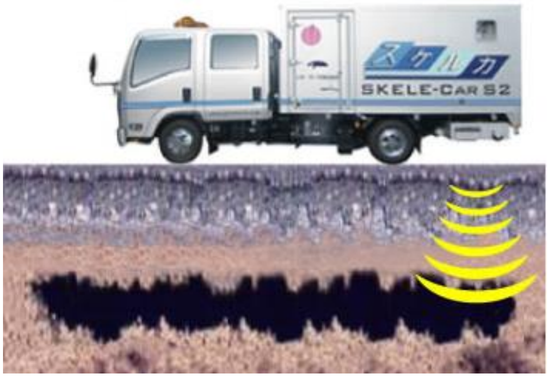

Figure 2. Probing vehicle for shallow cavities

To maintain roads efficiently, risk evaluation method shown in **Figure 3** is currently adopted. In this method the risk of cave-in occurrence is evaluated based on short side and depth of the cavity. If the plot of a cavity is in the area of high risk, the cavity is repaired with priority. However, this method is empirical and does not have scientific basis.

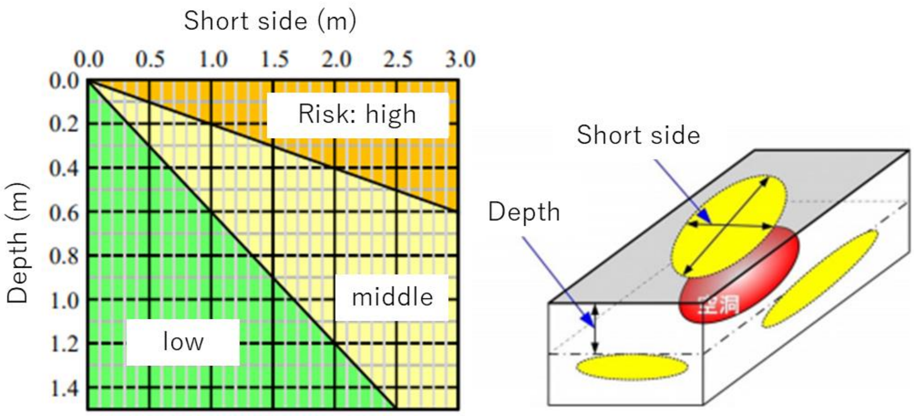

Figure 3. Current risk evaluation method

In this study, model tests simulating the cave-in formation and loading tests model ground with cavity were conducted to investigate the process of cave-in formation. Also, MLIT's reports on cavity/cave-in incidents were analyzed statistically to confirm the integrity with the experiment.

MODEL TESTS SIMULATING CAVE-IN FORMATION

The apparatus used in the experiment is schematically shown in **Figure 4**. It has a small opening at the bottom to simulate the damaged part of underground pipes. Dry sand was placed in the soil chamber and colored sand layer was put in front at every 2.5 cm to observe the deformation of the ground. The test procedure is as follows.

1. Water was supplied to the ground through side walls or bottom
2. After ground water level was stabilized, the opening was released by removing the plug put into the opening
3. Soil as well as water was drained through the opening
4. By repeating the cycle of water supply/drainage, a cavity gradually expanded and the surface layer eventually collapsed

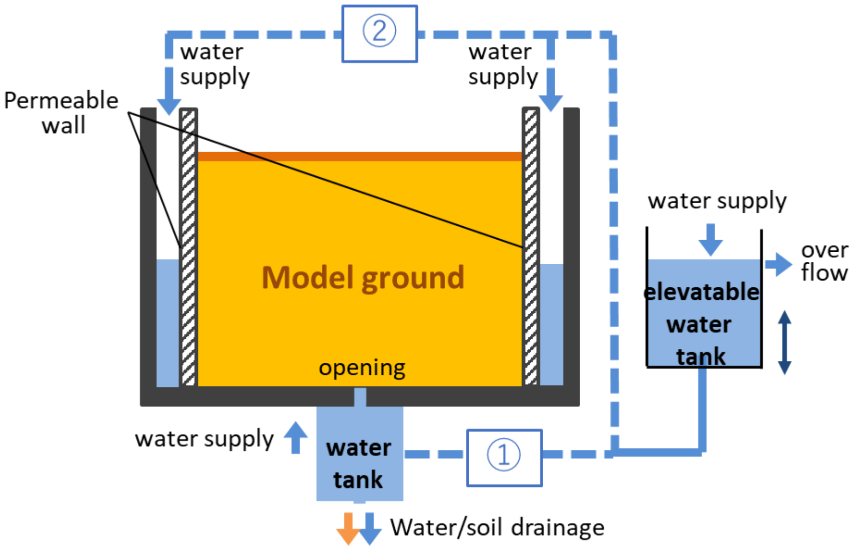

Figure 4. Schematic figure of the apparatus

Uniform silica sands of different grain size (D_{50}= 0.5 mm for Silica no.5, D_{50}= 0.2 mm for Silica no.7) were used for model ground.

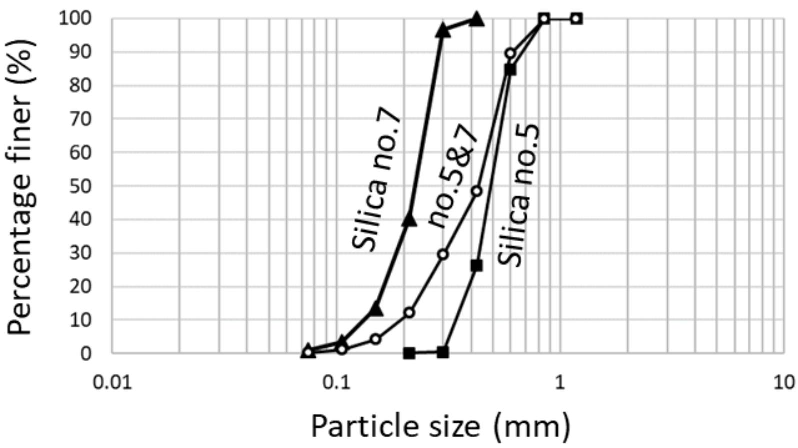

Figure 5. Grain size distribution of silica no.5 and 7

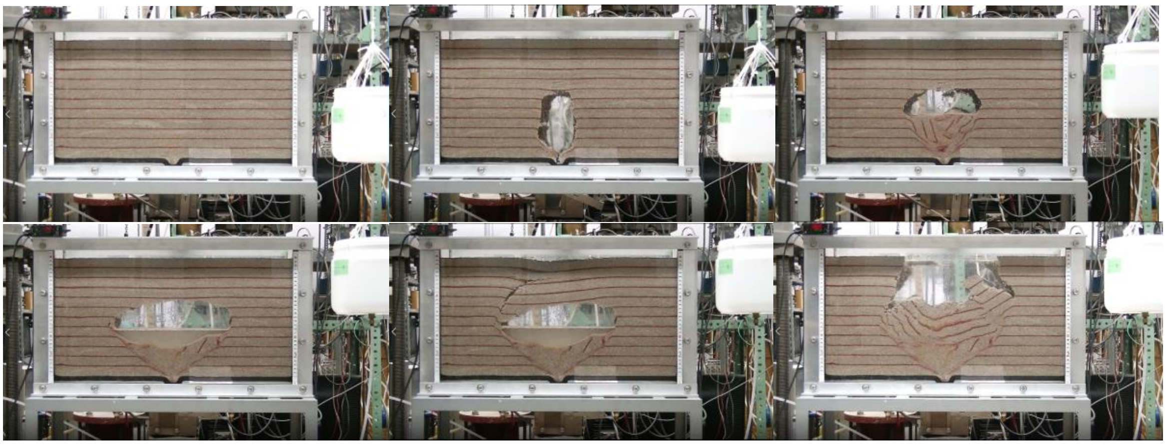

Figure 6. Typical example of cave-in formation

Based on the field survey conducted at national roads in Japan, Nakata (2018) reported that a cavity tends to expand horizontally rather than vertically. **Figure 7** shows the history of cavity expansion in the model tests. Each group of plots connected by line stands for how the thickness of covering soil and width of a cavity changed in each test. In general, width of a cavity tends to increase more than mean depth decreases. It means that a cavity tends to expand horizontally and this corresponds to the report by Nakata (2018).

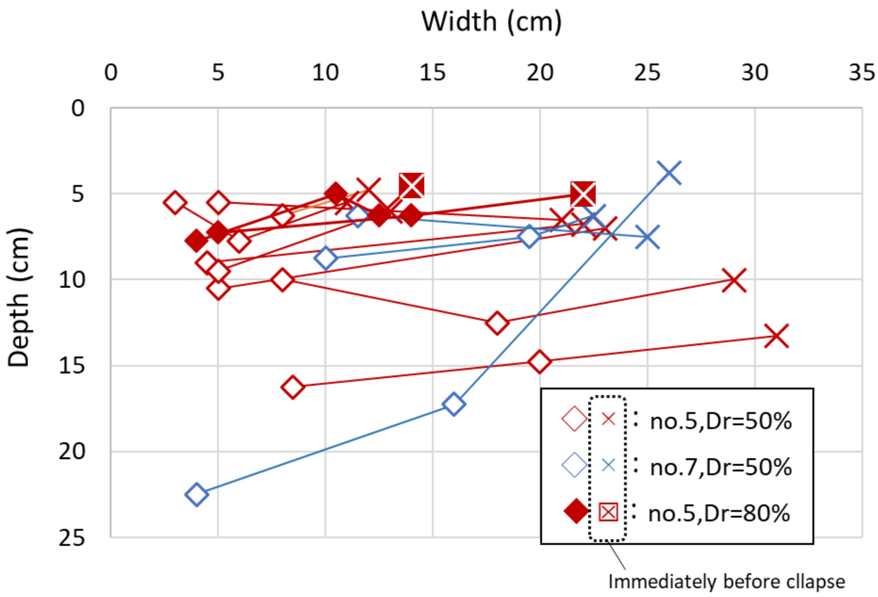

Figure 7. History of cavity expansion

Figure 8 shows the relationship between the mean depth and width of a cavity immediately before collapse. According to this figure, there seems to be correlation between mean thickness and width. Specifically, mean depth tends to increase with the increase in width. It means that depth should be larger to stabilize as width of a cavity increases. This relationship enables us to roughly estimate whether a cavity is stable or not. If the plot of a cavity is above the line, it means that the depth is not large enough to stabilize and the cavity is likely to collapse.

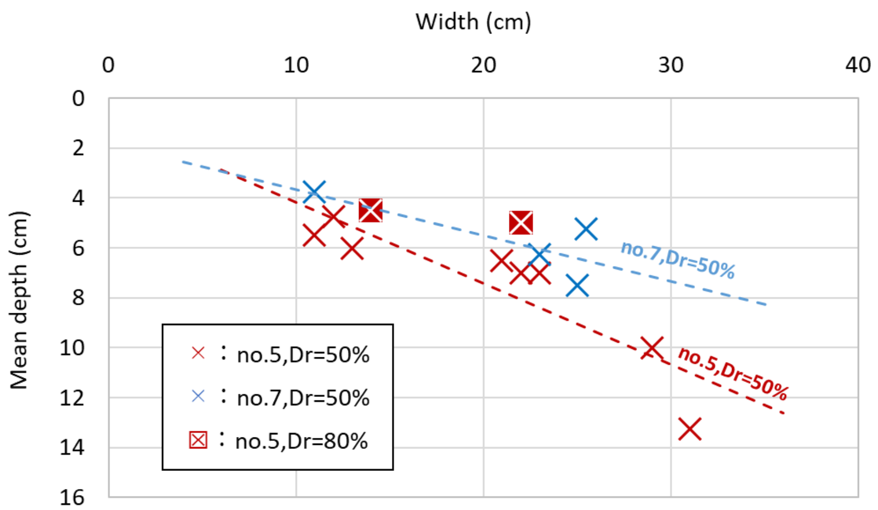

Figure 8. Mean depth vs. width of a cavity immediately before collapse

LOADING TESTS ON MODEL GROUND WITH CAVITY

Loading tests were conducted to investigate the behavior of ground having a cavity. Schematic figure of the tests is shown in **Figure 9**. Test procedure is as follows.

1. A cavity of approximately 5 cm width was made in the same way as the model tests.
2. Loading was applied on the surface of the model ground (the loading width was 5 cm and the loading speed was 1.1 cm/min).

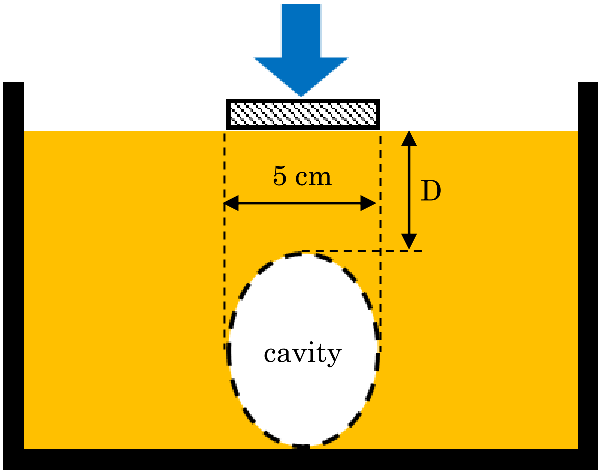

Figure 9. Schematic figure of loading tests

Figure 10. Loading machine

As shown in **Figure 11**, if there is a cavity in the ground, stress increased first and when the displacement exceeds a certain point it decreased. Compared to the cases with no cavity, it can be said that the ground becomes weak if it has a cavity. This tendency seems remarkable if the cavity is shallow.

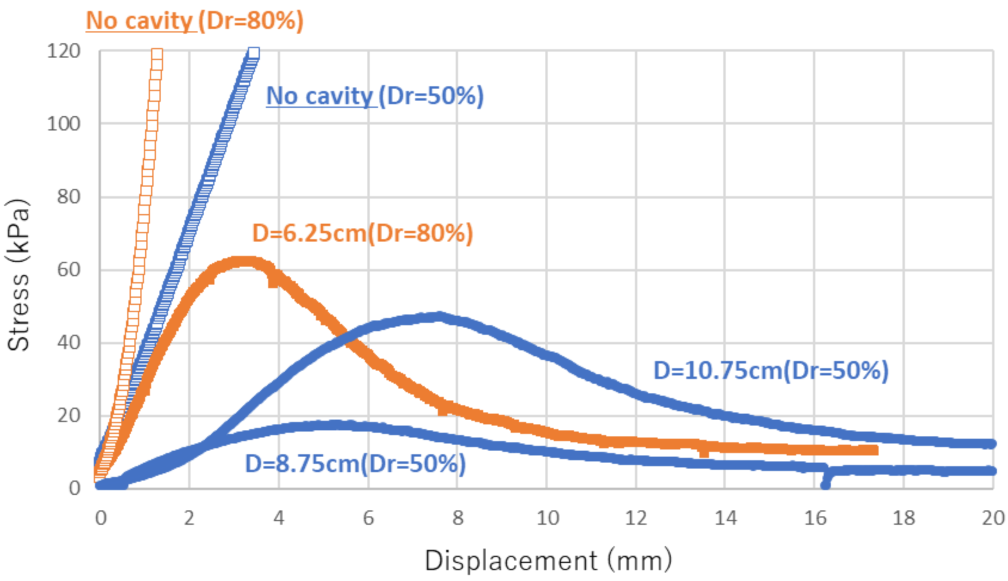

Figure 11. Stress vs. displacement

STATISTICAL ANALYSIS ON MLIT's REPORTs OF CAVITY/CAVE-IN

Based on MLIT's reports on cavity/cave-in incidents the relationship between short side and depth of real cavities were obtained as shown in **Figure 12**. Unfortunately, it was difficult to distinguish cavity case and cave-in case in the reports. Therefore, based on the information of remarks column cave-in cases were extracted. The plots of cave-in cases stand for the short side and depth of a cavity immediately before collapse. The short side and depth were obtained from digging investigation. According to **Figure 12**, there seems to be correlation between short side and depth for cave-in cases.

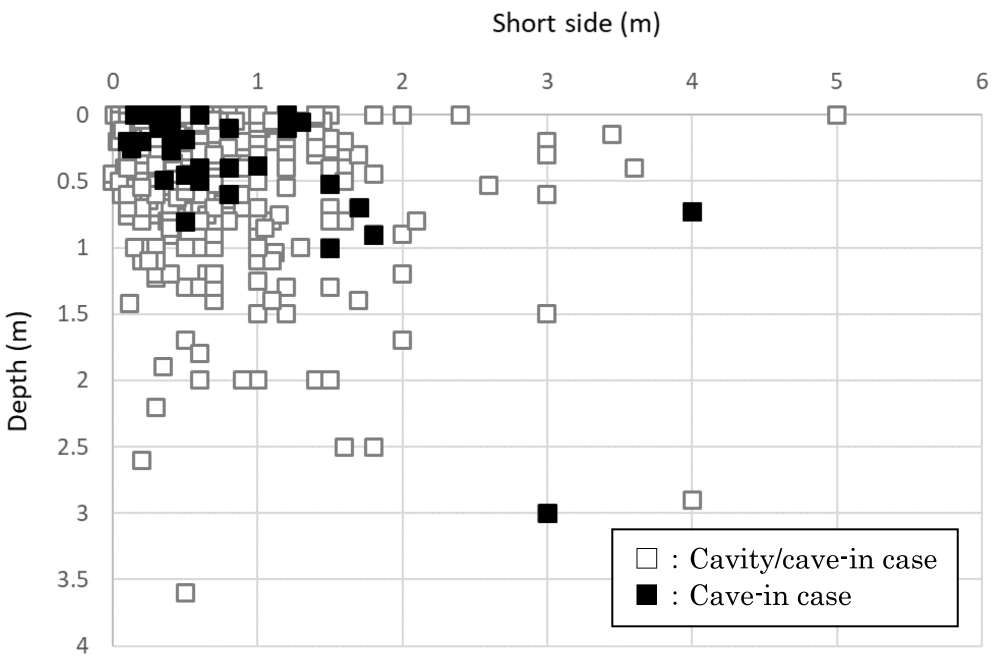

Figure 12. Short side vs. depth of cavities

The effect of seasons on the relationship between short side and depth of cave-in cases is shown in **Figure 13**. Based on the season the cave-ins happened, the plots are colored differently. If a cave-in happened from May to November (warm season), the plot is colored red, if December to April (cold season) blue. According to the figure, the red plots distribute lower than the blue plots. It seems because of the softening of pavements due to the relatively high temperature.

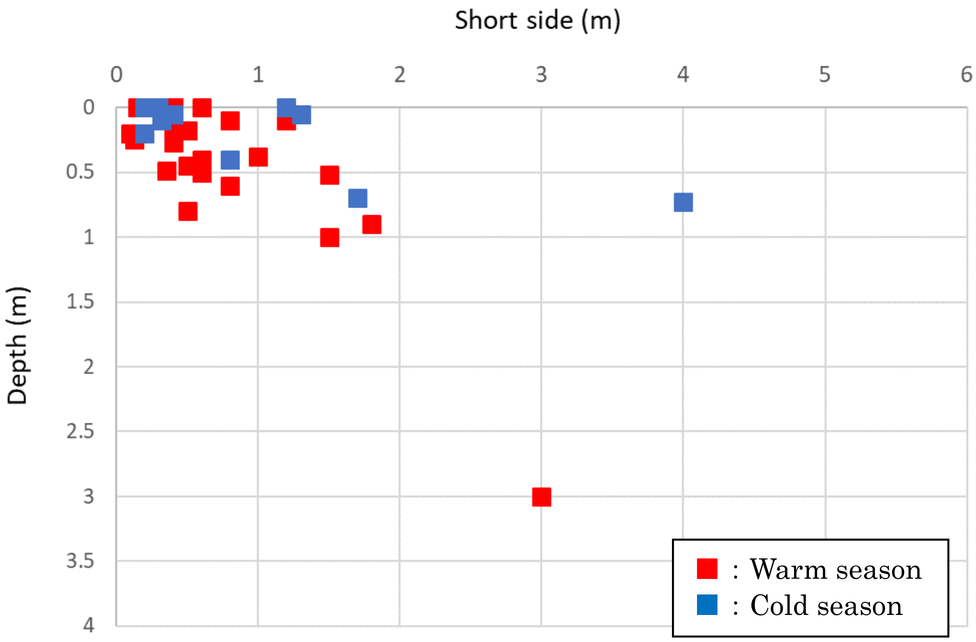

Figure 13. Short side vs. depth of cavities (effect of seasons)

CONCLUSIONS

Based on the model tests simulating cave-in formation, there seems to be correlation between mean depth and width of a cavity immediately before collapse. Since similar trend was observed in the statistical analysis on MLIT's reports, it seems reasonable to evaluate the stability of a cavity by short side and depth of the cavity.

ACKNOWLEDGMENT

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