Effects of buried structures on the formation of underground cavity

Effets des structures enterrées sur la formation d'une cavité souterraine

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ABSTRACT: The number of "cave-in" accident, a sudden collapse of the ground like a pitfall, has been increasing nowadays in urban roads. It is often caused by an underground cavity expansion without being noticed. A collapse happens when the cavity has reached the surface ground. Many cavities are found close to underground structures. Some of those cavities are caused due to the breakage of buried structures such as sewer pipes. Soil is flowed out from cracks of pipes with water. However, in some cases, obvious breakages were not found in underground structures. In those cases, it is not clear why cavities tend to be generated around buried structures. It is considered that water flows more easily around underground structures than in other part of the ground. Soil is carried with water flow around buried structures. In this study, a series of permeability tests and model tests was conducted to investigate the effects of buried structure on the formation of underground cavity.

RÉSUMÉ : Le nombre d'accidents dus à un affaissement, un effondrement soudain du sol comme dans une embuche, s'est accru dernièrement dans les voies urbaines. Ces accidents sont souvent causés par une cavité souterraine s'élargissant sans que l'on s'en aperçoive. Un effondrement se produit lorsque la cavité atteint la surface du sol. De nombreuses cavités se situent à proximité d'ouvrages souterrains. Certaines de ces cavités sont dues à la rupture de structures enterrées telles que les canalisations d'égouts. Le sol se répand dans les canalisations d'eau à travers les fissures présentes dans celles-ci. Toutefois, dans certains cas, des ruptures évidentes n'ont pas été décelées dans les ouvrages souterrains. Dans ces cas-là, la raison pour laquelle les cavités ont tendance à se produire autour de structures enterrées n'est pas claire. On considère que l'eau s'écoule plus facilement à proximité des ouvrages souterrains que dans d'autres parties du sol. Le sol est transporté par le flux d'eau autour des structures enterrées. Dans cette étude, une série d'essais de perméabilité et d'essais sur modèle a été réalisée pour examiner les effets des structures enterrées sur la formation de cavités souterraines.

KEYWORDS: cave-in, sinkhole, erosion, cavity, model test, permeability test, underground structure, pipe

1 INTRODUCTION

Cave-in accidents in urban area are mostly caused due to broken part of old buried pipes. Soil is washed out and flown into brakages with water. Then underground cavities are formed.[1)]

However, pipe's failure was not always found with underground cavities. The process of expansion of underground cavities in such cases is not clarified. One supposition is that; water flow is concentrated at the gaps between the ground and buried structures and soil is drained through this "water pathway".

In this research, influence of buried structure on the formation of underground cavity was evaluated by permeability test and model tests.

2 PERMEABILITY AT THE GAP OF THE GROUND

To investigate water permeability at the gap between a buried structure and the ground, permeability test was conducted. An acrylic cylinder was installed into the center of the constant head peameability test apparatus. Tested:material, relative density, cylinder's diameter and unevenness of the cylinder's surface were changed. An example of the test results is shown in Figure 1. Permeability coefficient with the cylinder was around 10% higher than that without the cylinder. In case that cylinder's surface was uneaven (0.2mm thickness, rectanglar block of the plastic tape) with crossing direction of water flow, permeability coefficient showed larger value.[2)]

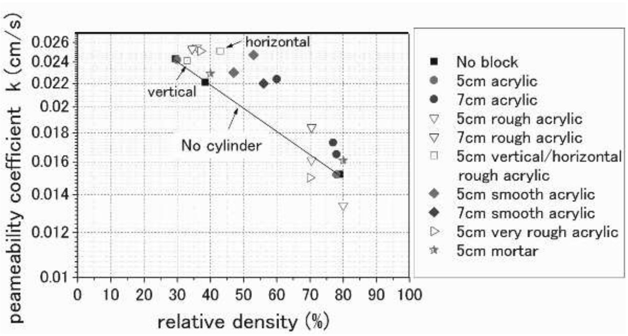


Figure 1. Permeability coefficient of constant head tests with/ without the cylinder (Toyoura sand)

Figure 2 represented the influence of slight shaking of the cylinder on permeability. Rotation of the cylinder made permeability increase in dense ground but decrease in loose ground, because rotation caused disturbance of the ground near the cylinder. It was suggested that small shaking of the ground caused increase of permeability around buried structures.

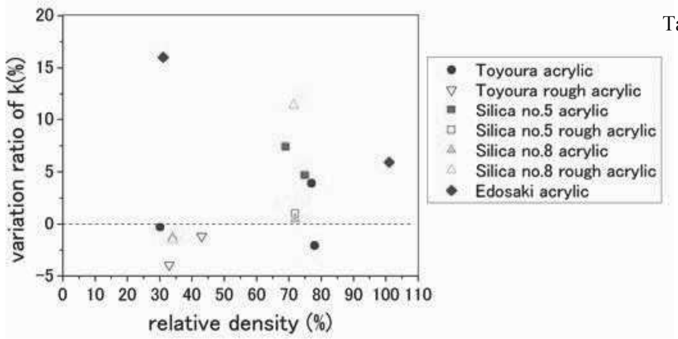


Figure 2. Effect of cylinder's small shaking on permeability

Table 1. Test conditions with Constant & Horizontal water flow condition

Code	Material	Position of the block	Dc or Dr (%)	Water level(cm)	Ratio of soil outflow(%)	Elapsed time (sec)
Sn	Silica no.5	None	Dr 80	7.5	7.8	---
Tf	Toyoura	L far	Dr 80	10	15.4	220
Ta	Toyoura	Above	Dr 80	10	7.1	220
Ts	Toyoura	Side	Dr 80	10	11.5	270
Vn	Volcanic	None	Dr 80	10	0	150
InD	Improved	None	Dc 90	10	0	340
InL	Improved	None	Dc 75	10	0.4	150

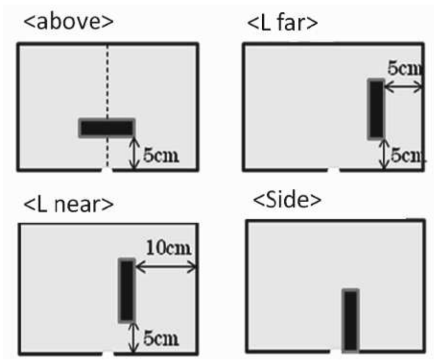


Figure 5. Positions of the block

3 MODEL TEST WITH CONSTANT WATER LEVEL

3.1 *Test apparatus and conditions*

Test apparatus is schematically shown in Figure 3. This apparatus is composed of three parts: center soil chamber, right and left side water chambers. Porous stones were put between the soil chamber and water chambers, and bottom plate of the soil chamber. Through the porous stone, water was penetrated freely. There was a 5mm width opening at the center of the bottom plate of the soil chamber, which was closed initially. A wooden block (2.1cm length, 10cm height, 8cm width) was put into the ground with various positions, which simulated a buried structure. It was painted and water penetration was prevented. Positions of the block were shown in Figure 5. Overburden weight was equivalent to the weight at 100cm deep of the ground. Toyoura sand, silica sand no.5, improved soil and volcanic soil were used. The improved soil was utilized at construction site, and the volcanic sand caused a sinkhole accident Particle size distributions of tested materials are shown in Figure 4. All test cases are shown in Table 1.

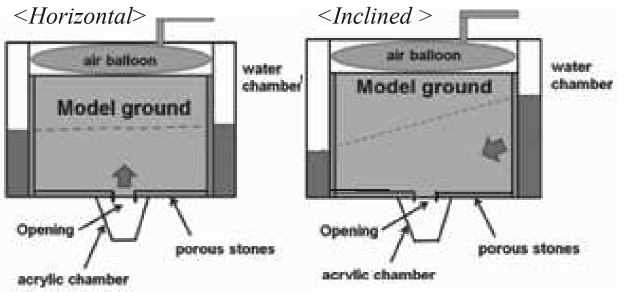


Figure3. Schematically figure of the soil chamber with constant water level

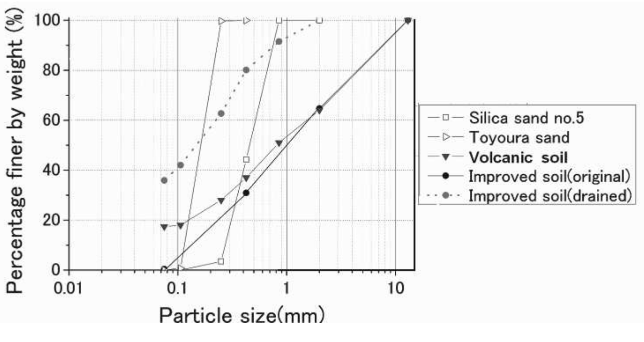


Figure 4. Particle size distribution

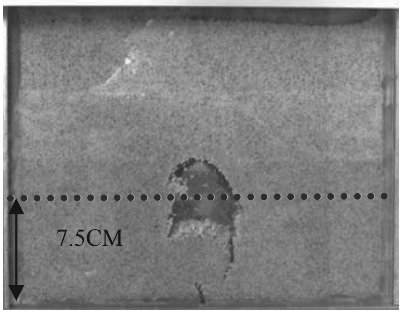
3.2 *Test procedure*

The model ground was compacted on around optimum water content. Water was penetrated from the bottom porous stone plate or side water chamber, until horizontal or inclined water level was kept steadily. After the model ground became stable, opening was released and then water and soil was flown out from the opening

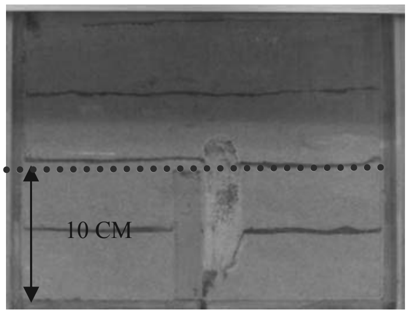
3.3 *Test result*

Position of the block changed the situation of the cavity formation. Dotted line in Figure 6 represented the water level just before the opening released. When water level was inclined and water was flown from right to left as shown in Figure 7, cavity was generated below the block but overall tendency of the formation was similar as the case without the block. From Figure 7, it was suggested that water was penetrated around the block by putting blue ink to water.

Improved soil prevented soil outflow in dense condition but a cavity was expanded in loose condition. Particle size distribution of drained soil was investigated and the result was shown in Figure 4. It was suggested that drained soil contained much more fines than original material. The amount of fines in drained soil of case InL was 50% of whole amount of fines in the model ground, which proposed that fines flown out from large area. Test results of horizontal water flow conditions were shown in Table 1. " Ratio of soil loss" in Table 1 means ratio of weight of soil loss to total dry weight of soil in the model ground." Elapsed time" in Table 1 means time which took to achieve the specified water level (10cm) which indicates permeability. From Table 1, position of the block influenced not on rise of water level but on soil outflow. On the other hand, increasing of water level was very rapid in volcanic soil which didn't cause soil outflow. Loose condition of improved soil caused much more rapid rise of water level than dense condition of that which suggested the risk of soil outflow in large hydraulic gradient.

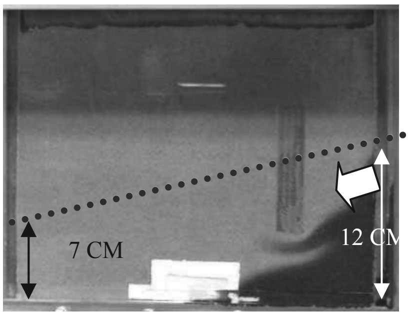


A) Sn, $w_{initial}$=10%



B) Ts, $w_{initial}$=10%,

Figure 6. Cavity formation of the model test with horizontal water level



TOYOURA SAND, DR=80%, W_i=10%, Lfar, Water level L:7cm R:12cm

Figure 7. Water penetration around the block with inclined water level

4 MODEL TEST WITH REPETITION OF WATER PENETRATION

4.1 *Test apparatus and conditions*

Test apparatus was composed only of the center soil chamber. This soil chamber size is 30cm long, 20cm high, 5cm wide. It has the 5mm width opening at the center of the bottom plate and soil was drained from there. Two patterns of water supply point: "Opening" and "Side wall", were set as presented in Figure 8. Overburden weight was equivalent to the weight at 100cm deep of the ground. A wooden block (2.1cm length, 10cm height, 5cm width) was set into the ground with 4 kinds of the position.(as shown in Figure 4) Toyoura sand was used and particle size distribution was shown in Figure . In Lfar test case, colored sand layer was made in every 3cm thickness. Table 2 was shown the test conditions.

Table 2. Test conditions with Repetition of water penetration

Code	Material	Position of the block	Initial Water content (%)	Dr (%)
TOpn	Toyoura	None	10	Dr 80
TOpf	Toyoura	L far	10	Dr 80
TOpne	Toyoura	Lnear	10	Dr 80
TOpa	Toyoura	above	10	Dr 80
TOps	Toyoura	side	10	Dr80
SiOps	Silica no.5	sude	10	Dr80
SiOpn	Silica no.5	None	10	Dr80
TSwf	Toyoura	Lfar	10	Dr80
TSwne	Toyoura	Lnear	10	Dr80
TSwa	Toyoura	above	10	Dr80
TSws	Toyoura	side	10	Dr80

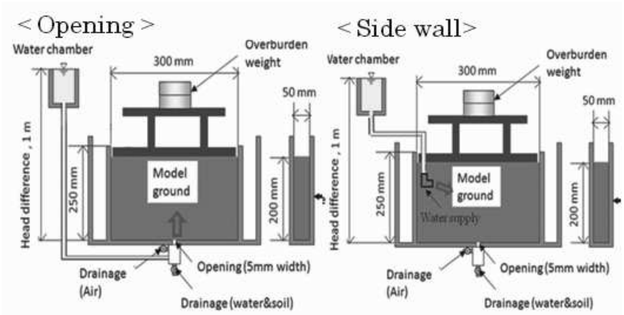


Figure 8. Schematically figure of test apparatus with repetition of water penetration

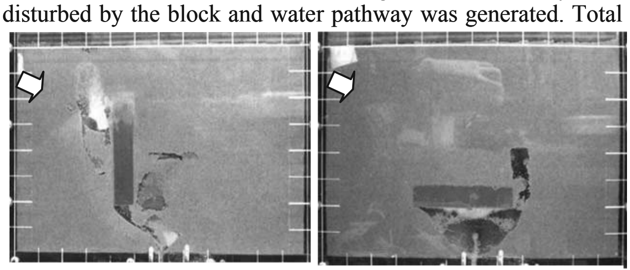
4.2 *Test procedure*

Model ground was compacted on around 10% water content. Approximately 100cc water was supplied with head difference of 100cm. Water supply cycle was repeated until the cavity reach ground surface.

4.3 *Test Result*

Cavity formations of TSwne and TSwa are shown in Figure 9. Arrow signified the direction of water supply. If water was supplied from horizontal direction, cavity was generated around the block. In TSwf test case, water content was measured at several points as shown in Figure 10. Figure 10 suggested water content was not uniform in the model ground. It was supposed that water flew from water supply to the opening and passed through the right side of the block.

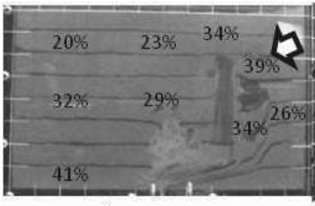
Dry weight of drained soil was measured in each cycle, and ratio of cumulative soil loss to total weight of soil in the model ground was calculated. Rapid soil loss was observed in the test case which the block didn't disturb water flow (such as TOps and TOpa cases). Although the cavity expansion was stopped after a certain cycle in the test case without the block because amount of water is not enough for reaching to the top of the cavity and breaking the arching of the ground, it didn't stop in that with the block. Ground arching around a cavity was disturbed by the block and water pathway was generated. Total

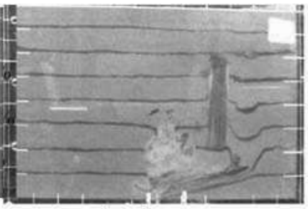


a) TSwne, 7th water supply b) TSwa, 7th water supply

Figure 9. Cavity formation with repetition of water penetration

soil loss was larger in the all cases with block than that without the block.

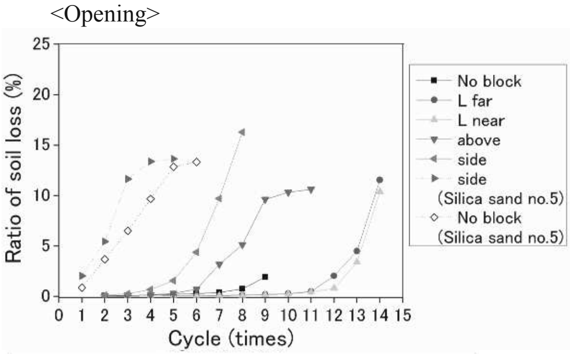




TSwf, 12th water supply
Figure 10. Distribution of water Content in the model ground

TSwf, 10th water supply
Figure 12. Loosening expansion

<Opening>



<Side wall >

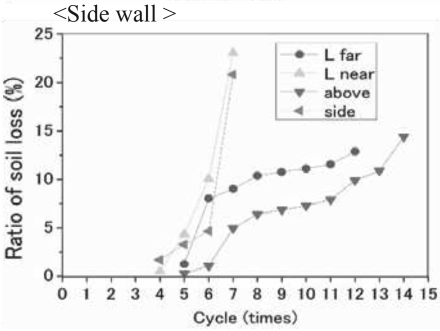


Figure 11.Cumulative ratio of soil loss in each water

5 DISCUSSION ABOUT PROCESS OF THE CAVITY AND LOOSENING EXPANSION

Loosening (low density area) was often generated around the cavity. (1 Deformed area around the cavity was observed in LfarTSw test case by colored sand layers, which was represented in Figure 12. Later this deformed area became the cavity as observed in Figure 10. It was obvious that soil outflow from the cavity area. However, measured soil loss was not equivalent to that from the cavity. It was proposed that this phenomenon was caused by two different processes: 1) expansion of loosening, and 2) soil loss from loosening area.

In the process of 1) expansion of loosening, it was supposed that expansion of loosening caused cavity's shrinkage. Area of loosening and area of cavity was estimated from photographs taken during the tests and then ratio of loosening area to cavity area was calculated. As shown in Figure 13, ratio increased rapidly and then decreased. The test cases which the block was set at Lfar and Lnear positions, the ratio increased much more than other cases. This process easily happened in clean uniform materials such as Toyoura sand and Silica sand no.5. Renuka et al.(2011) evaluated the stiffness of loosening by cone penetration test and found that penetration resistance decreased in loosening area[3)].

In the second process, it was suggested that fine particles were flown out from loosening. This process was caused in well graded materials. (Referring to 3.2) Kenny et al.(1985). suggested that particles which were larger than four times of fine particles were necessary for this process.[4)] Mukunoki et al.(2007)[5)] revealed by CT scanner that formation of loosening was different from Toyoura sand and natural sand(Referring to Figure 13), because Toyoura sand was clean uniform sand but natural sand was well graded sand.

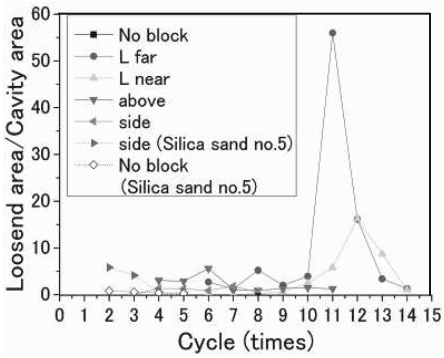


Figure 12. Evaluation of loosening

<TOYOURA>   <NATURAL >

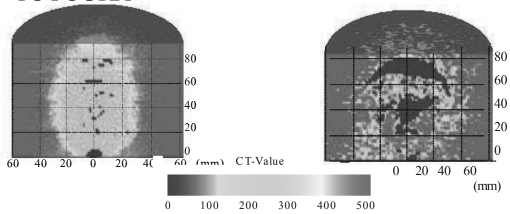


FIGURE 13. Measurement of loosening and cavity by CT scanner, Mukunoki et al.(2007)[5)])

6 CONCLUSION

This paper suggested that the placement of block in the model ground changed water penetration and sometimes promoted expansion of the cavity. In addition, gaps between buried structures and the ground had higher water permeability than that in the normal ground. The increase of water permeability and concentration of water penetration around underground structures may be caused in the practical ground. Two different processes of generation of loosening are proposed.

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