International Journal of GEOMATE, July 2023, Vol. 25, Issue 107, pp.149-157
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2023.107.3836
Geotechnique, Construction Materials and Environment

EXPERIMENTAL STUDY ON THE GENERATION OF ODOR DURING RAINWATER INFILTRATION PROCESS

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*Corresponding Author, Received: 28 Feb. 2023, Revised: 09 March 2023, Accepted: 02 April 2023

ABSTRACT: Although it is known that the generation of odor is one of the precursory phenomena of landslide disasters, the mechanism by which offensive odors are detected before landslides is not fully clarified. It has been reported that high odor intensity was observed from the pore air in soil at 0-3m depth on natural slopes with a history of landslide disaster history. In this study, laboratory experiments were conducted to examine the possibility of the generation of odors during rainwater infiltration process. We made a model ground mixed with odorants and conducted the following two experiments, 1) measurement of odor intensity on the surface of 10 cm height soil layer when the groundwater level rose by injecting water from the bottom, 2) measurement of odor intensity on the surface during rainwater infiltration process using a 1 m height soil layer and a laboratory rainfall device. From these tests, it was found that there is no or very little increase in odor intensity on the surface in the process that the pore air in soil was released from the surface accompanied by the rainwater infiltration. However, in both tests, the measured odor intensity increased rapidly when the ground water level approached the surface. It can be said that the generation of odor as a precursor phenomenon can be caused when the level of groundwater containing odorants reaches near the ground surface.

Keywords: Odor, Landslide disaster, Groundwater, Rainwater infiltration, Precursory phenomenon

1. INTRODUCTION

In recent years, the frequency and intensity of landslide disasters particularly debris flows caused by heavy rains have increased and threated human life on an unprecedented scale. In Hiroshima Prefecture, 74 people died in the Hiroshima landslide disaster that occurred in August 2014 [1], and 87 people died mainly due to debris flows in Western Japan Heavy Rain Disaster that occurred in July 2018 [2]. Although numerous case studies have been conducted in various countries [3], [4], [5], in the present situation, where large-scale debris flows frequently occur, how to at least reduce the number of victims is an urgent issue.

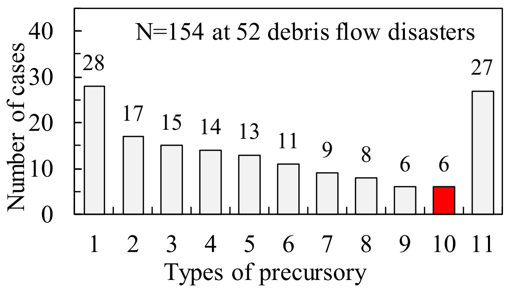
Since many of the victims of these disasters were residents living in landslide hazard areas, there is a strong need for effective measures to encourage early evacuation of people living in these high-risk areas. One way to reduce the human damage is to publicize the premonitory phenomena of disasters.

It is known that several premonitory phenomena exist before the occurrence of landslide disasters [6]. Precursors of debris flows are listed below.

- Collapsing slopes near mountain streams, falling rocks
- The turbidity of river water. A drop in the water level of a mountain stream while it continues to rain
- Earth and sand runoff and driftwood mixed into turbid water. Sparks in the stream.
- Rumbling of the ground, rumbling of mountains
- Sound of rocks hitting each other
- Smells of rotten soil

These precursory phenomena are not reported in all disasters, and appear differently in each disaster.

The Ministry of Land, Infrastructure, Transport and Tourism collected and analyzed information on precursory phenomena confirmed by residents of 52 debris flows and 12 landslides that occurred in Japan in 2004 and 2005 [7]. In the report, 154 cases of precursor phenomena were collected from



1. Rumbling of the earth, rumbling of the mountains, 2. Sound of boulders colliding, 3. Turbidity of running water, 4. Rise of river water level, 5. Occurrence of driftwood and fallen trees, 6. Drastic drop in water level, 7.Slope spring/ surface flow 8. Slope failure/ crack, 9. Sediment runoff, 10. Offensive Odor, 11.Others

Fig.1 Summary of 154 cases of precursory phenomena confirmed at 52 locations of debris flow disasters (modified from [7])

52 debris flows disasters. Figure 1 shows the classification of 154 precursory phenomena. As shown in the figure, there are many auditory phenomena such as the rumbling of the ground, rumbling of mountains, and the sound of boulders hitting each other, and visual phenomena related to water such as turbidity of running water and rising river water levels. On the other hand, the occurrence of odor was reported in 6 out of 52 debris flows. Furthermore, regarding when the occurrence of the odor as a precursory phenomenon was confirmed, 2 cases occurred 1 to 2 hours before the occurrence of debris flow, 2 cases occurred 30 to 1 hour before, and 2 cases occurred 1 to 30 minutes before.

Although it is known that the generation of offensive odors is an omen of debris flow disasters, there are very few studies on the physical mechanism by which the generation of odor is a precursor of landslide disasters. As a basic survey to clarify this point, Tsuchida et al. measured the odor intensity in the ground on the natural slope where the surface layer of 0.5m to 5m is covered with Masado [8]. Masado, a sandy soil formed by weathering the granite, is common in western Japan and almost every year the debris flows are caused by heavy rain [9], [10]. Figure 2 shows the method of measurement. Using a penetration hole of a lightweight dynamic cone penetration test. The odor intensity at the depth was measured by connecting a Teflon tube and to an odor measuring instrument through an aluminum pipe. Figure 3 shows measured odor intensity with the depth and the penetration resistance. The maximum odor intensity measured was 1047, which was comparable to kimchi (Korean pickled cabbage) and coffee, representative foods with strong odors.

It is considered that the presence of strong odor in the pores in the ground is caused by microorganisms contained in the soil. According to the recent study of soil microbiology [11], [12], [13], it is estimated that tens of millions to hundreds of millions of individuals and tens of thousands of species of bacteria exist in 1g of soil, and among them there are many microorganisms whose evolutionary lineage and metabolic functions are unknown. It is thought that the odors distributed in the ground are a composite of the odors of compounds calculated by these various microorganisms.

Assuming that the strong odor existing in the ground is the origin of the odor as a precursor, the next question is why the odor is generated before the debris flow. According to the results of surveys of large-scale debris flow disasters, it is often speculated that a smaller-scale debris flow occurred before the debris flow that carried a large amount of sediment (Tsuchida et al., 2018, Hashimoto et al., 2019). In such cases, it is conceivable that odors were released from the section of the stratum

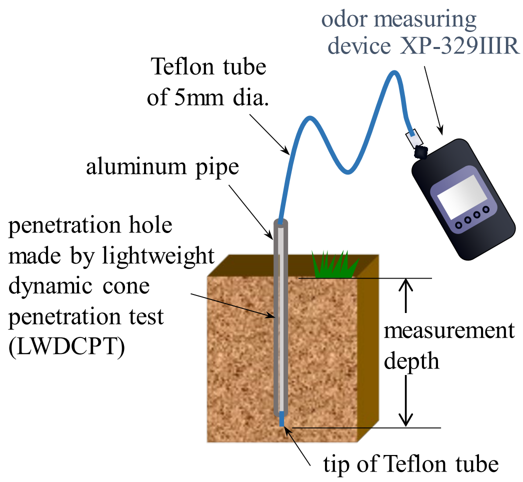


Fig.2 Measurement method of underground odor intensity using penetration holes of lightweight dynamic cone penetration test [8]

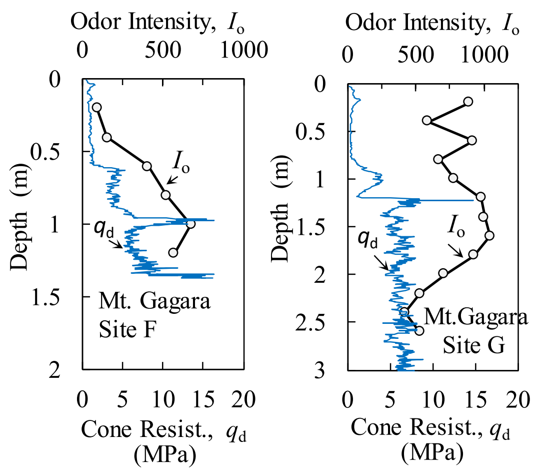


Fig.3 Measurement example of odor intensity in the ground (Modified from [8])

exposed due to the slope failure or ground erosion caused by the debris flow that occurred earlier in the vicinity. In this case, the preceding events of debris flow is the cause of the odor generation.

On the other hand, in the report of the Ministry of Land, Infrastructure, Transport and Tourism, there were 6 cases of odor precursors, 2 of which were 1 to 2 hours before the occurrence and 2 of which were 30 minutes to 1 hour before the occurrence. From the survey of the disaster area, even if there was a preceding debris flow, the maximum time difference was around 20 minutes, and it is difficult to explain the occurrence of odors from 30 minutes to 2 hours before the debris flow by the preceding event.

The next possible cause of odor is the movement of water in the ground. The surface layer of the slope is usually unsaturated. When heavy rain continues, a large amount of rainwater infiltrates into the ground, and in this process, the pore air in

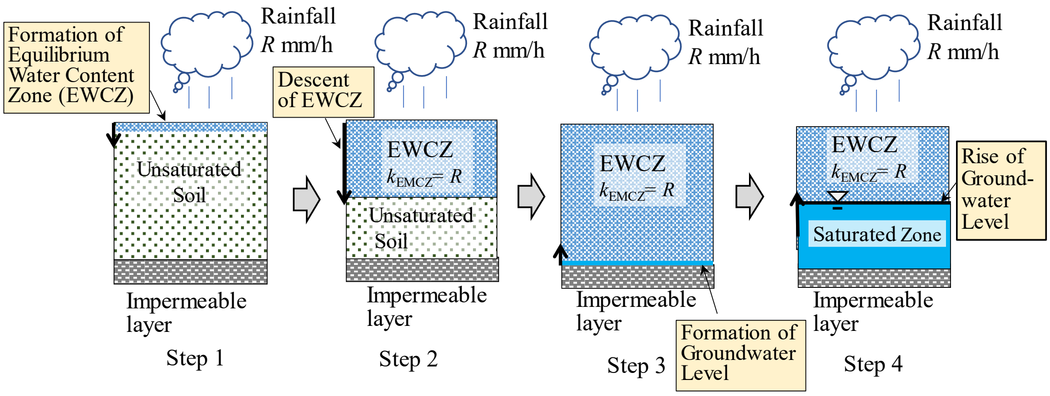


Fig.4 Process of infiltration from ground surface and formation of groundwater level when rainfall intensity is constant [14], [15]

soil containing odors is released to the ground surface.

The process of infiltration from ground surface and formation of groundwater level when rainfall intensity is constant is shown in Figure 4 [14], [15]. In Fig.4, when rain falls on the unsaturated ground, the rainwater begins to infiltrate into the ground from the upper layer (Step 1). In the infiltrated zone, the hydraulic conductivity also increases as the volumetric water content increases. When the hydraulic conductivity of the infiltrated zone increases until it becomes equal to the rainfall intensity R, an equilibrium state is reached. At this time, the infiltrated layer descends at a constant rate while maintaining a constant volumetric water content. In this study, the infiltrated layer under the equilibrium is named the equilibrium water content zone (EWCZ), and the hydraulic conductivity at this state is shown as k_{EWCZ}, which is equal to R (Step 2). When EWCZ reaches the impermeable layer of the basement, the rainwater begins to accumulate in the ground, saturating the ground from the bottom, forming the groundwater level (Step 3). The groundwater level gradually rises from the lower layer to the upper layer (Step 4). In this infiltration processes shown in Fig.4, the air in the pores in soil is replaced by the rainwater and released to the ground surface.

To study the occurrence of odor during the rainwater infiltration process, we made a one-dimensional soil tank that partially contain the source of odors. A laboratory test was carried out on the generation of odors on the ground surface during the infiltration process. Based on the results, the relationship between the generation of odors and the rainwater infiltration was discussed.

2. RESEARCH SIGNIFICANCE

Government public office of Japan and many local governments have informed people that odors are precursors of landslide disasters. However, there is no physical explanation as to why odors are a precursor to landslide disasters. This study investigates the possibility of explaining the generation of odor by the infiltration of rainwater during heavy rainfall and the subsequent behavior of groundwater. Many studies have been conducted on rainwater infiltration and groundwater behavior, but very few studies have focused on odors. If the causes of odors are clarified, residents will be able to make more correct decisions and reduce the number of victims of disasters.

3. ODOR INTENSITY ON THE SURFACE WHEN GROUNDWATER LEVEL RISES DUE TO WATER INJECTION

3.1 Experimental Method

Using a soil tank containing odor substance, the odor intensity on the surface was measured when the groundwater level was rising by injecting water from the bottom. Figure 5 shows the apparatus of odor generation experiment by water injection. As shown in Fig.5, a 10 cm height soil layer containing odor substance was prepared in a circular soil tank with an inner diameter of 30cm, a height of 20cm and a porous stone on the bottom. The water was injected by the pump from the bottom of the soil layer to rise the groundwater level, and the odor

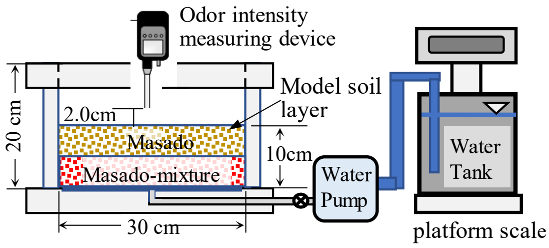


Fig.5 Apparatus of odor generation experiment by water injection from the bottom of soil tank

intensity was measured at 2.0 cm above the center of the surface.

The soil used for the experiment was Masado adjusted to a void ratio 0.90 and a saturation degree of 30%. The Masado used was collected from Mt. Gagara on the campus of Hiroshima University, and had an average particle size of 0.90 mm and a fine particle content of 8.7%.

The soil containing odor substances was made by mixing 400g kimchi (Korean pickled cabbage) with 5cm thick Masado Layer. The soil layer composition was the following two types.

Soil type A: the top 5 cm is the Masado, and the bottom 5 cm is the Masado-kimchi mixture.

Soil Type B: the top 2 cm is Masado, middle 5 cm is Masado-kimchi mixture and bottom 3 cm is Masado layer

A water injection experiment was conducted one day after the model soil layer was prepared. A constant flow rate of water was evenly injected through the porous stone from the bottom using a pump. During the water injection, the groundwater level in the soil layer was calculated at each time by measuring the weight of injected water, and at the same time, the position of the groundwater level was visually confirmed. The water injection was continued until the water level in the ground reached the surface of the soil layer.

3.2 Experimental Results and Discussion

Figure 6 shows the relationship between the groundwater level (G.W.L.) and the odor intensity measured at the surface, when the rate of G.W.L. rise is 0.31 cm/min in soil type A. In this case, the odor intensity increased to 30 in 24 hours after the soil layer was prepared. The water level reached the surface about 21 minutes after the start of water injection. The odor intensity on the surface remained almost constant at an average of 43.6 until the groundwater level reached 8 cm. Although pore air containing odor should have been discharged by the water injection, no significant change in odor was observed on the surface. When the groundwater level reached 8 cm, the odor intensity increased rapidly and the maximum intensity was 184, which was measured just before the groundwater level reached the ground surface.

Figure 7 shows the result of soil type B, in which the rate of G.W.L. rise was 0.43 cm/min. In the case of soil type B, since a 5 cm thick soil layer with odor was installed at a depth of 2 cm from the surface, the odor intensity on the surface increases to 136 in 24 hours after the soil layer was prepared. After the start of water injection, the average value of odor intensity on the surface remained almost unchanged, although the odor intensity repeatedly increased and decreased by about ±15 until the G.W.L. reached 8.6 cm. When the G.W.L. approached around 8.6 cm, the odor intensity rapidly increased and reached a maximum value of 332.

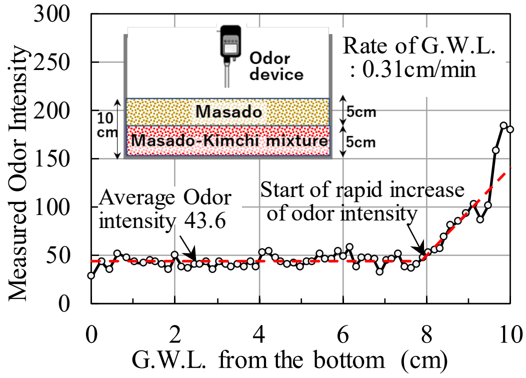


Fig.6 Odor intensity with G.W.L. in the water injection experiment (rate of G.W.L. rise 0.31 cm/min, odor mixing depth 5-10cm)

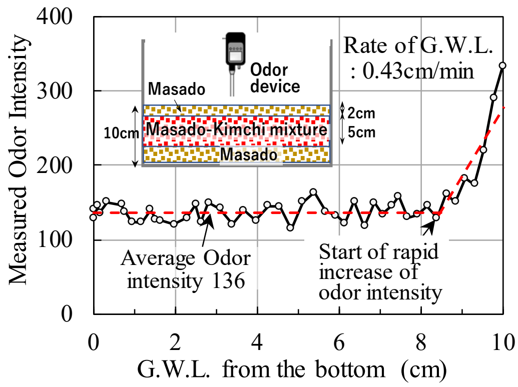


Fig.7 Odor intensity with G.W.L. in the water injection experiment (rate of G.W.L. rise 0.43 cm/min, odor mixing depth 2-7cm)

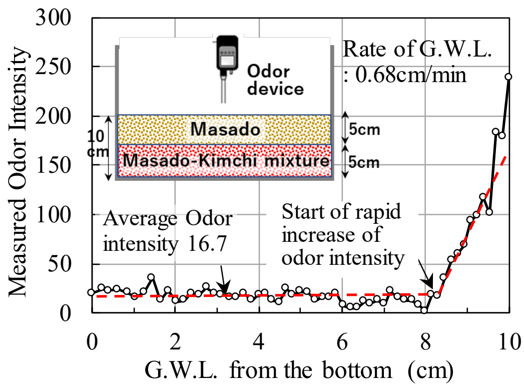


Fig.8 Odor intensity with G.W.L. in water injection experiment (rate of G.W.L. rise 0.68 cm/min, odor mixing depth 5-10 cm)

Figure 8 shows the test result of soil type A when the rate of G.W.L. rise was 0.68 cm/min. The odor intensity, which was 19.0 before the start of water injection, almost unchanged with the average

16.7 after the water injection. The odor intensity started to increase to 240 when the water level became 8.0 cm. As this was almost consistent with Fig.6, the rate of G.W.L. rise had almost no effect on the generation of odor.

In previous experiments, the upper part of the circular soil tank shown in Fig.5 was open. As odors have the property of being strengthened and diluted by air currents and wind, it was seen that the measured odor intensity was affected by changes in air currents in the laboratory from the variations in measured values after the start of the experiment in Fig.6-8. Another water injection experiment was carried out under the condition that the top of the circular soil tank was covered with a vinyl sheet to reduce the effects of air currents in the laboratory. Figure 9 shows the results of the experiment. The tendency that the odor intensity increased rapidly after the groundwater level reached 8 to 9 cm was the same as previous experiments shown in Figs.6-8. However, As shown in Fig.9, the variation in the measured odor intensity is clearly reduced. Further, the odor intensity 71 at the beginning of the experiment gradually increased as the G.W.L. rose, and reached 114 before the odor intensity started to increase rapidly. It is thought that this was due to the odor of pore air which was replaced and released by the water injection. It is estimated that the release of odorous pore air with the rise of G.W.L. also occurred in the experiments in Figs 6-8, but that the odor was diluted by the influence of the air current and was not measured as the increase of odor intensity as shown in Fig.9.

Summarizing the above results, the odor intensity increased rapidly when the G.W.L. reached about 8-9 cm (1-2 cm below the surface) in all experiments. The rapid increase in odors at this stage will be due to that the groundwater containing odorous substances approached to the odor intensity measuring device which located at 2.0 cm over the surface. Fig. 9 showed that, when the soil tank was sealed, the odor intensity increased gradually after the start of water injection. The increase will be due to the release of pore air containing odorous substances. However, the increase of odor intensity in this process was much smaller than that after the rapid increase started. In other words, it can be said that the main cause of odor generation was not the release of odor-containing pore air, but the approach of odor-containing groundwater to the ground surface.

4. ODOR GENERATION DURING THE INFILTRATION PROCESS UNDER CONTINUOUS RAINFALL

4.1 Experimental Method

A one-dimensional model experiment was

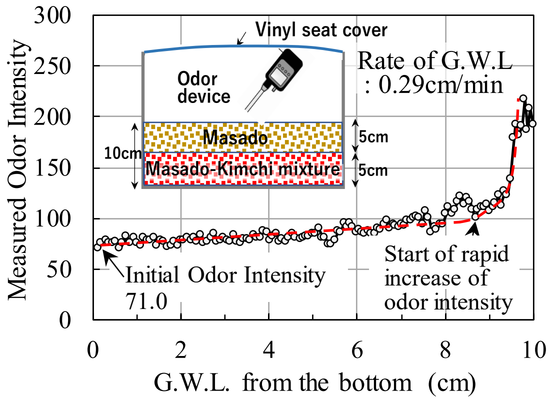


Fig.9 Odor intensity and G.W.L. in water injection experiment (with vinyl sheet cover, rate of G.W.L. rise 0.29 cm/min, odor mixing depth 5-10 cm)

conducted in order to investigate the rainwater infiltration and the generation of odors. Figure 10 shows an outline of the experimental setup. Toyoura sand with a void ratio of 0.75-80 was used for the soil layer. Toyoura sand has a density of 2.675 g/cm^3 and a permeability coefficient of 1.02×10^{-2} cm/s measured by a constant water permeability test. The profile soil moisture meter is a device that measures the soil moisture distribution at several points in the depth direction in the cross section of the embedded soil layer in the vertical direction. Soil moisture content was measured at 5 depths. The rainfall device was designed to spray fine water droplets from nozzles by adjusting the air pressure and water pressure.

As shown in Fig.10, at the bottom of an acrylic soil tank, 3 cm height odorant was placed. On the odor substance, 97-cm-thick soil layer was made with Toyoura sand, which was divided into 20 layers of 5 cm each and compacted. A profile soil moisture

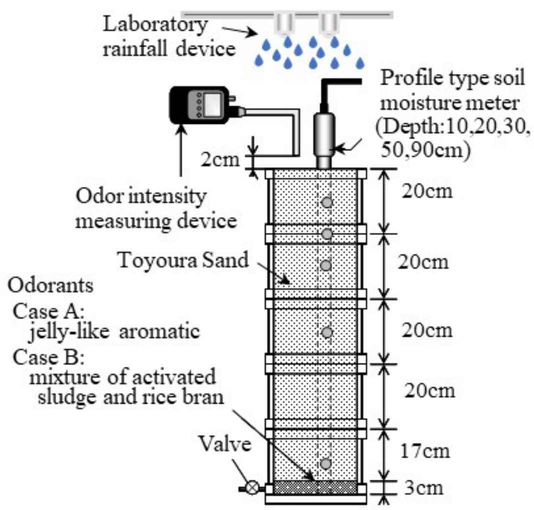


Fig.10 Model soil tank and test equipment used for odor generation experiment during rainwater infiltration

meter was installed in the process of preparing the soil layer, and the measurement points of the soil moisture meter were set at depths of 10 cm, 20 cm, 30 cm, 50 cm, and 90 cm. The odor sensor was installed so that the tip of the Teflon tube for suction came to a height of 2 cm from the center of the soil surface. Following 2 odorants were used in the experiment;

Case A: commercially available jelly-like air freshener that is a mixture of highly absorbent polymer and aromatic oil,

Case B: rice bran fermented with activated sludge that was used for sewage treatment at the Higashi-Hiroshima Purification Center.

The odor intensities of air freshener and rice bran, which was measured at a distance of 2 cm, were 868 and 631, respectively,

The rainfall experiment was started 24 hours after preparing the soil layer. The rainfall intensity of the experiment was 20mm/h. During the experiment, the water contents in the ground and the odor intensity were measured. The lower end of the soil tank was not drained while rain was applied.

4.2 Experimental Results and Considerations

In the experiment using air freshener as an odorant (Case A), the odor intensity on the surface increased to 66 during 24 hours after the preparation. The rainfall continued 780 minutes. Figure 11 shows changes in volumetric water content in the ground with the rainfall time. As shown in the figure, at 30 minutes after the rainfall was started, an equilibrium water content zone (EWCZ) was formed near the surface with a volumetric water content of about 20%. The EWCZ descended at an almost constant rate from 30 minutes, 60 minutes and 90 minutes. At 120 minutes, the lower end of the EWCZ reached a depth of 90 cm. Then EWCZ reached the bottom (97cm) and the ground saturation started from the bottom. At 240 minutes, the depth of 90cm was saturated. A free water surface was formed in the saturated ground, and the groundwater level rose at an almost constant rate, reaching a depth of 50 cm at 480 minutes, a depth of 30 cm at 540 minutes, a depth of 20 cm at 600 minutes and a depth of 10 cm at 720 minutes, respectively. Finally, the groundwater level (G.W.L.) reached near the surface of the ground.

Figure 12 shows the degree of saturation at 5 depths with the rainfall time. In the figure, it is shown that the degree of saturation of EWCZ was around 50±3%. It can be seen that the G.W.L. rose as the saturation progressed from the bottom, which indicated that the process of infiltration progressed as shown in Fig. 4. In Figure 13 the arrival of EWCZ and the arrival of G.W.L. at 10 cm, 20 cm, 30 cm, 50 cm and 90 cm depths are shown with the rainfall time. The measured odor intensity on the surface is also shown for the comparison. As shown in Fig.13, the descent rate of EWCZ was 0.66 cm/min, and the ascent rate of the G.W.L. was 0.21 cm/min. The odor intensity dropped from 66 to 0 immediately after the rainfall was started, and did not change at all after that, but increased rapidly when the G.W.L. reached near the ground surface. The reason why the odor intensity decreased immediately after the rainfall was thought to be that the odor components in the air decreased due to the absorption by rainwater. After the immediate drop of the odor intensity, no odor intensity was measured until the G.W.L. reached the surface. From the result, it can be said that the increase of odor intensity was due to the fact that the groundwater containing odorous substances was exposed to the surface and that the odor intensity of released pore air with the rise of the G.W.L. was not measured.

The experimental results of Case B using rice bran fermented with activated sludge as the odorant are shown in Figure 14 and Figure 15. In this

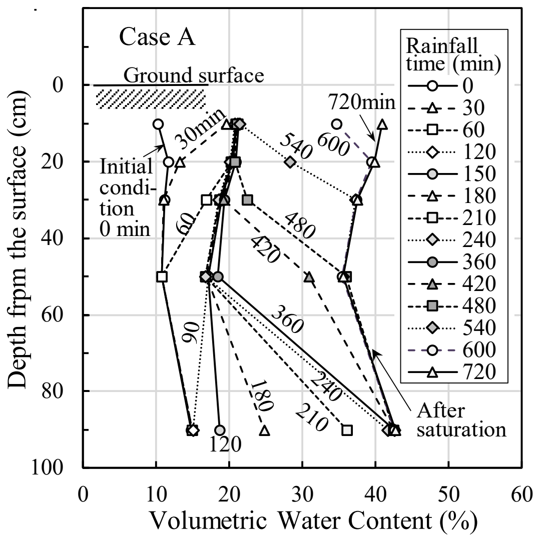


Fig.11 Change in volumetric water content in the ground due to rainwater infiltration (Case A)

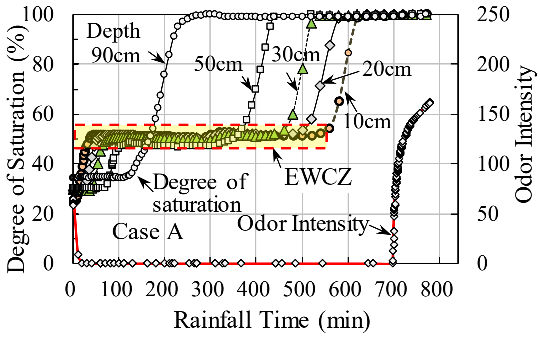


Fig.12 Degree of saturation at 5 depths and odor intensity on the surface with rainfall time (Case A)

experiment, the odor intensity increased to 172 before the rainfall started. The rain continued for 700 minutes. Unfortunately, as the sensors at depths of 50 cm and 90 cm of the profile type soil moisture meters were out of order, the change of water content at these depths were not measured. Fig.14 shows the degree of saturation at 3 depths with the rainfall time. As shown in Fig.14, after rainfall was started, the EWCZ with about 50% degree of saturation was formed in order from the upper layer as well as Fig.12. In the second half of the experiment, it is shown that 30 cm depth was saturated at 520 minutes, 20 cm depth at 550 minutes and 10 cm at 600 minutes, respectively. Fig.15 shows the arrival of EWCZ and the arrival of G.W.L. at 10 cm, 20 cm, 30 cm depths. Although the descent rate of EWCZ, 0.42cm/min and the ascent rate of G.W.L., 0.31cm/min were slightly different from those in Fig.13, the rainwater infiltration process of Case B was almost similar with that of Case A. The measured odor intensity on the surface was 172 before the start of the experiment, and there was almost no change until it rapidly increased to 300 at the 600 minutes of rainfall time. As shown in Fig. 15, in Case B, the rapid increase of odor intensity started when the G.W.L. was 10-20 cm below the surface, not reaching the surface.

5. CONSIDERATION ON OCCURANCE OF ODOR DURING RAINWATER INFILLTRATION

In order to investigate the relationship between the occurrence of odor and rainfall infiltration, we made a model ground mixed with odorants and conducted the following two experiments.

Experiment 1: Measurement of odor intensity on the surface when the water level rises by injecting water from the bottom of 10 cm soil layer.

Experiment 2: Measurement of odor intensity on the surface during rainwater infiltration process (using a 1m soil layer and a rainfall device)

In Experiment 1, there was almost no increase in odor intensity on the ground surface until the groundwater level reached 8 cm from the bottom (2 cm above the ground surface). This result was not affected by the position of the layer containing odor in the soil layer or the injection rate of water. In an experiment in which the upper part of the soil tank was sealed, the odor intensity on the ground surface gradually increased at a constant rate from the start of the injection until the point where the odor intensity rapidly increased from 71 to 100. This increase from the start is thought to be due to the released pore air in soil containing the odor components. However, the increase of odor intensity during this process was far less than the rapid increase in odor intensity (from 100 to 220) when the groundwater level reached near the ground surface.

In Experiment 2, when a jelly-like air freshener was used (Case A) as an odor source placed at the bottom 3cm of a 1m-high soil tank, the intensity of the odor on the surface decreased immediately after the start of rainfall. After that, the odor intensity did not change at all during the rainwater infiltration

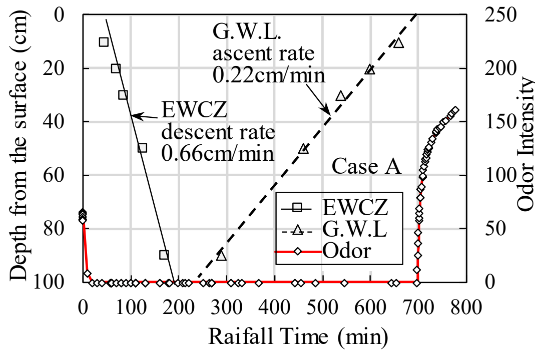


Fig.13 Arrival time of EWCZ, arrival time of groundwater level (G.W.L.) and odor intensity in the rainwater infiltration process (Case A)

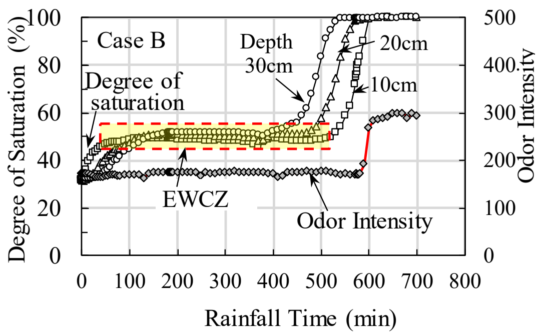


Fig.14 Degree of saturation at 3 depths and odor intensity on the surface with rainfall time (Case B)

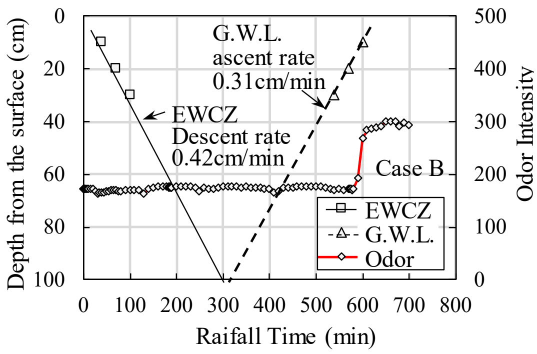


Fig.15 Arrival time of EWCZ, arrival time of groundwater level (G.W.L.) and odor intensity in the rainwater infiltration process (Case B)

process shown in Fig.4, but it increased rapidly when the groundwater level reached near the surface. In experiments using a mixture of activated sludge and rice bran as the odor source (Case B), there was no decrease in odor intensity immediately after the start of rainfall, and almost no change in odor intensity during the rainfall infiltration process. The odor intensity increased rapidly after when the groundwater level reached 10-20 cm below the surface.

Considering the results of Experiments 1 and 2, it can be said that there is no or very little increase in odor intensity on the ground surface in Step 2 and Step 3 in Fig.4 where the pore air in soil was released from the ground accompanied by the rainwater infiltration. On the other hand, when water in the ground containing odorous substances reached near the surface or was exposed to the surface, the odor intensity increased rapidly. In this laboratory experiment, it was found that the generation of odor as a precursor phenomenon can be caused by the formation of a groundwater level the rise of the groundwater containing odorants near the ground surface. This speculation about the reason why odor is a precursor phenomenon, is based on the experimental results conducted under limited conditions. To verify the validity of the speculation, further research is necessary, including the investigation of groundwater behavior in the field where the odor occurred as a precursor phenomenon.

6. CONCLUSIONS

Although it is known that the generation of odor is one of the precursory phenomena of landslide disasters, the mechanism by which offensive odors are detected before landslide disasters is not fully clarified. It has been reported that high odor intensity was observed from the pore air in soil at 0-3m depth on natural slopes with a history of landslide disaster. In this study, laboratory experiments were conducted to examine the possibility of the generation of odors during the rainwater infiltration process. We made a model ground mixed with odorants and conducted the following two experiments, 1) measurement of odor intensity on the surface of 10 cm height soil layer when the groundwater level rose by injecting water from the bottom, 2) measurement of odor intensity on the surface during rainwater infiltration process using a 1 m height soil layer and a laboratory rainfall device.

The main conclusions can be summarized as follows.

- In the experiments of 10 cm height soil layer, there was almost no increase in odor intensity from the start of water injection, and the odor intensity increased rapidly when the groundwater level reached 8-9 cm. The rapid increase in odor intensity is considered to be due to the fact that the groundwater containing odorants reached near the ground surface.
- In the experiment where the upper part of the soil tank was sealed, the odor intensity on the surface gradually increased at a constant rate from the start of the water injection. The increase from the start is thought to be due to the released pore air containing odor components, but the increase in odor intensity during this process was much smaller than that after the rapid increase later.
- In the experiments of the 1 m height soil layer, the odor intensity near surface did not change at all during the rainwater infiltration process, but increased rapidly when the water level approached the surface and was finally exposed on the surface.
- From both tests, it was found that there was no or very little increase in odor intensity on the surface in the process that the pore air in soil was released from the ground accompanied by the rainwater infiltration. However, in both tests, the measured odor intensity increased rapidly when the ground water level approached the surface. It can be said that the generation of odor as a precursor phenomenon can be caused when the level of groundwater containing odorants reaches near the ground surface. To verify the validity of the speculation, further research is necessary, including the investigation of groundwater behavior in the field where the odor occurred as a precursor phenomenon.

7. ACKNOWLEDGMENTS

This research was supported by Grants-in-Aid for Scientific Research Project No. 20K04085 from the Ministry of Education, Culture, Sports, Science and Technology, Japan and Japan Society for the Promotion of Science. The authors would like to express deep gratitude to the support.

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