京都大学防災研究所年報 第48号 C 平成17年3月
Annuals of Disas. Prev. Res. Inst., Kyoto Univ., No. 48C, 2005

Detection of Collapse Position in Mountainous Slope by Underground Sound Method

Yasuyui TADA*, Masaharu FUJITA*, Daizou TSUTSUMI*, Takenobu OKUMURA**, Kan KOYAMA***, Takayuki KAWAI****

* Disaster Prevention Research Institute, Kyoto University.
** Faculty of Agriculture, Tottori University.
*** Tottori Prefectural Forest Experimental Station.
**** The United Graduate school of agricultural Science, Tottori University.

Synopsis

In Japan, a lot of hillslope collapses triggered by heavy rainstorm almost every year. In spite of continuous effort to elucidate the mechanism of landslide occurrence, sufficient answers explaining why the particular position of the hillslope collapses have not been obtained. It has been pointed out that there is a close relationship between the landslide and underground water paths according to observations around the collapse site; i.e. outlet of soil pipes on the scarp, clouding, stopping or spouting of spring water just before or after the landslides. However, detail of these relationships has not been clearly understood yet, partly due to lack of an effective method to detect the water path at the slope.

In this study, a new method to detect the underground water path positions measuring sound of ground water flow by a sound sensor "hydrostat" was developed. As a first step, water flow through a single water pathway installed within an isotropic model soil layer was examined by this method. And as a second step, this method was applied to natural hillslopes and road cut slopes. Water springs from lower part of every slope were observed. As the results, underground sound pressure above the spring was biggest than other positions. Therefore, underground water path positions can be estimated by this new method.

As a next step, this method was applied to the collapses in natural slope and road cut slopes. Measurement line was set up upper the scarp of collapse. And, underground sound pressure was measured at 2.0m intervals. Underground sound pressure in collapse position was bigger than other positions. Therefore, it was clear that the collapse position was decided by the water path position.

The non-failure position that had big underground sound was monitored. This position was collapsed by the typhoon in 2004. As the result, there is a part which underground water daily concentrates in the slope. And, water path position was collapsed by the groundwater that was supplied to torrential rains.

Keywords: underground sound, water path, collapse position

1. Introduction

In Japan, a lot of hillslope collapses triggered by heavy rainstorm almost every year. In spite of continuous effort to elucidate the mechanism of landslide occurrence (Okunishi et al. 1978, Okimura et al. 1980, Ohsaka et al. 1992), sufficient answers explaining why the particular position of the hillslope collapses have not been obtained. It has been pointed out that there is a close relationship between the landslide and underground water paths according to observations around the collapse site; i.e. outlet of soil pipes on the scarp, clouding, stopping or spouting of spring water just before or after the landslides (Tada et al. 2002). However, detail of these relationships has not been clearly understood yet, partly due to lack of an effective method to detect the water path at the slope.

In this study, a new method to detect the underground water path positions measuring sound of ground water flow by a sound sensor "hydrostat" was developed. As a first step, water flow through a single water pathway installed within an isotropic model soil layer was examined by this method. And, as a second step, this method was applied to natural hillslopes and road cut slopes. And, underground sound was compared with water path position.

As a next step, this method was applied to the collapses sites in natural slope and road cut slopes. Measurement line was set up upper the scarp of collapse. And, underground sound pressure was measured at 2.0m intervals. Underground sound pressure in collapse position was compared with other positions. And characteristics of underground sound in collapse position were examined. Moreover, variation of landform that was caused by the torrential rains was monitored. And, position of landform variation and characteristics of underground sound distribution were compared.

2. Underground sound and measuring device

In this paper, the sound generated from the underground flow is called the underground sound. Not only the underground flow originates but also another noises contains the underground sound. For instance, vibration sound of wind and stridulation sound of soil or gravel etc. Though, the noise can be suppressed by devising the measurement. Hereafter, it explains the mechanism of the measuring device.

Photograph 1 showed the underground sound measuring device. And figure 1 showed the measuring method of an underground sound. This device was developed to detect the water leak part of water pipe. This device is called the hydrostat in that field.

Measuring device of underground sound is composed of pickup sensor, measurement equipment, headphone, and recorder. The functions of each part are as follows.

[1] Pickup sensor; A stainless stick of φ0.8×10cm shown in photograph 1 is installed in the pickup sensor to prevent the noise such as the winds. This is inserted to the ground surface, and an underground sound is caught.

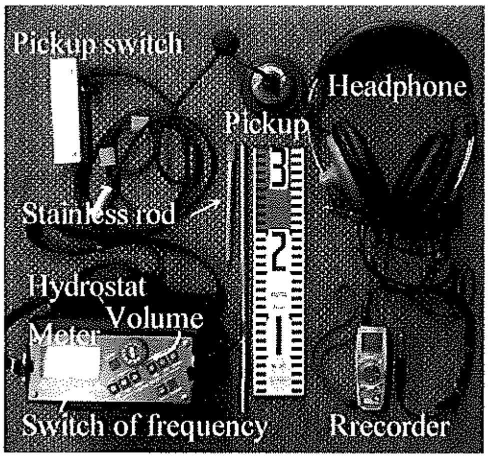

Photo 1 the underground sound measuring device.

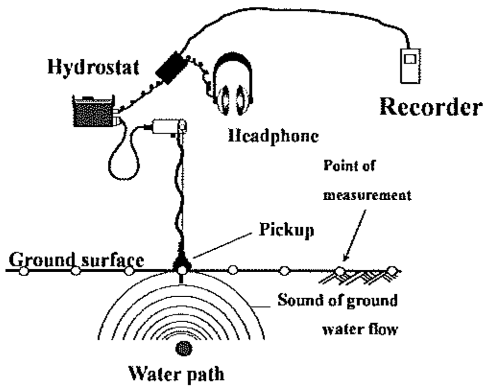

Fig. 1 Measure the underground sound

[2] Measurement equipment; this part consist of amplification circuit, filter circuit and level meter. The amplification circuit amplifies the underground sound that caught with the pickup sensor. The filter circuit intercepts the noise such as the winds, and take out the underground sound clearly. This function can flexibly correspond to various noises on the fields. The level meter directs the sound pressure of the underground sound. Strength of that sound can be visually judged by this function.

[3] Headphone; the underground sound caught with the pickup sensor is output with the amplification rate and the frequency band.

[4] Recorder; The underground sound output to the headphone can be recorded.

The underground sound measuring device can be used in the mountainous area. It is because that this device is light (total weight 900g) and also small.

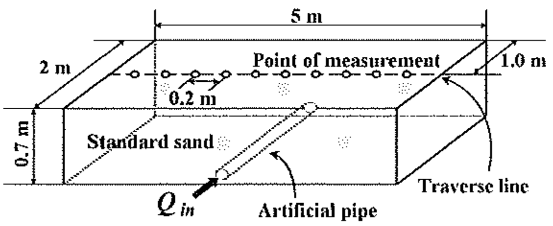

Fig. 2 model soil layer

Table 1 Experimental condition

Depth of artificial pipe (m)	Q (m?/sec)
	50
0.35	100
	150
	200
0.62	250
	300

3. Basic characteristics of the underground sound

To know the basic characters of an underground sound, the experiment with a model and the field investigation were done. In the following, it explains details.

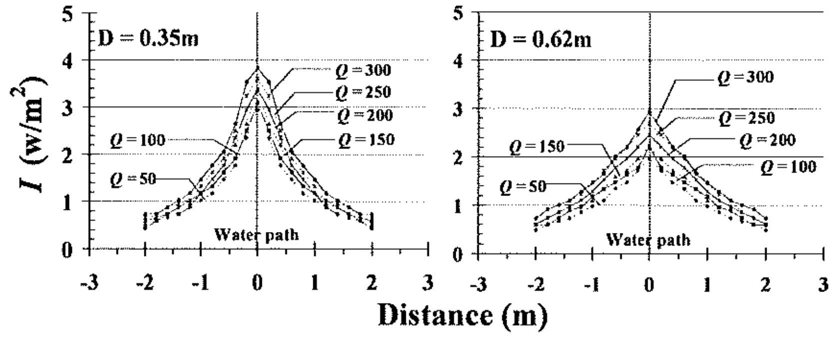

Fig. 3 Measurement results of underground sound in each depth

3.1 Method

Underground sound distribution is examined, when one water path exists in uniform soil layer. The model soil layer was shown in Figure 2. The model soil tank is 5m in length, 2m in width, and 0.7m in depth. The soil layer was made by the standard sand that was spread in the tank to become dry density was 1.43g/cm^3. Artificial pipe that assumed water path was set up at the center of this model soil layer.

Artificial pipe made of the chloromethane tube of 5cm in the diameter that have 0.8mm holes become to the density of 0.7 pieces/cm^3. Water was supplied from Q_{in} of Figure 2. Water passed the model soil layer drained in a point about 10m away from soil layer. And, the drain sound is not transmitted to the proving ground.

Experimental conditions changed depth of the pipe and the volumetric flow. That is, depth of the pipe is two cases (35 and 62cm), and steady volumetric flow is six case(50, 100, 150, 200, 250 and 300 mℓ/sec). Experimental conditions were settled in Table 1.

An underground sound was measured on ground surface. The measurement length is 2m, and the pipe has been buried at the center of the measurement area. The measurement interval is 0.2m.

An underground sound pressure is identified according to the following procedure. First, hearing sound from the headphone and the value of the level meter are carefully observed, next, the value of the upper limit is read. This underground sound could be caught well between 100-600 Hz in the result of a preliminary experiment. In this experiment, this frequency band is treated as observed value.

3.2 Characteristics of underground sound measuring in ground surface

Figure 3 showed the distribution of underground sound pressure of each pipe depth. Figure 4 showed the distribution of underground sound pressure of each discharge. In addition, the number in each figure showed the discharge (mℓ/sec) , and the position of the pipe is written as 0m in figure. The following can be read from figure.

[1] The underground sound pressure measured in the ground level is the largest on the pipe. An underground sound pressure becomes small away from the pipe that is the sound source. (fig. 3, 4)。

[2] In the case of the pipe depth is equal (Figure 3), the underground sound becomes big when there is a lot of flowing.

[3] in the case of the discharge from the pipe is equal (Figure 4), the underground sound becomes big when there is a shallow pipe.

These results give the following finding.

[1] The underground sound pressure is strongest on the water path. And the underground sound pressure becomes smaller far from the water path position.

[2] In the case of water path depth is same, the underground sound becomes big when there is a lot of flowing.

[3] In the case of water path flowing quantity is same, When the depth of water path is shallow, the peak of an underground sound pressure is bigger.

[4] The strength of the underground sound level transmitted to the ground surface is depend on the balance of flowing quantity and the water path depth.

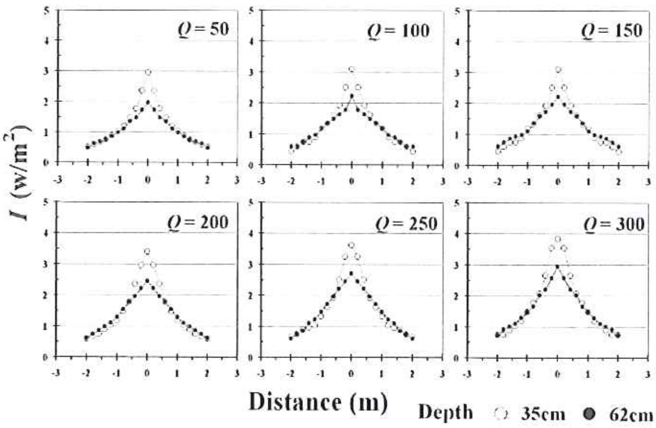

Fig. 4 Measurement results of underground sound in each discharge

4. Application of this technique to the natural slope

When only one water path exists in uniform soil layer, water path position was able to be presumed by underground sound peak. In this section, we discuss about the Presumption accuracy of water path position in the natural slope that had inhomogeneous soil layer

4.1 Outline of study area

The investigations are done in Misasa in Tottori Prefecture, Hirusen in Okayama Prefecture, Mt. Rokko in Hyogo Prefecture and in Kamitakara village in Gifu Prefecture. Study area was shown in Figure 5. The outlines of each study areas are as follows.

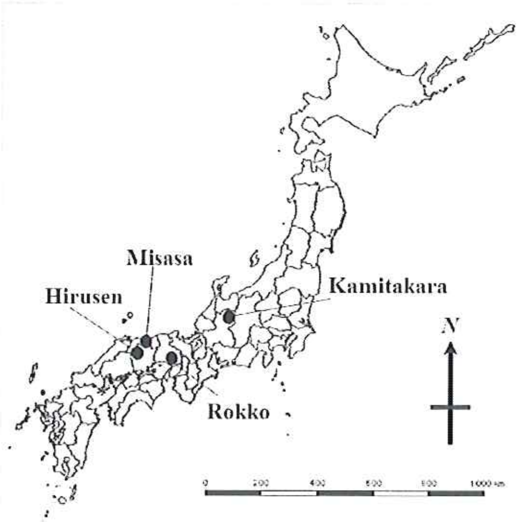

Fig. 5 Study area

[1] Hirusen A (Photo2) ; Spring position in forest road cut slope was inquired. Ground surface is covered with the andosol of 0.5 m in thickness. And the lower soil layer is composed of tuff breccia. There is one spring in tuff breccia soil layer. Spring occurred in heavy rainfall event or snow melting event. There were a few spring waters when the investigation was executed.

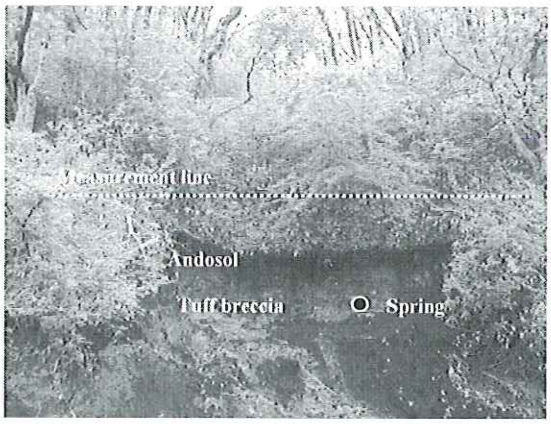

Photo 2 Soil exposure at the road cut in Hirusen A

[2] Hirusen B (Photo3) ; Two spring position in forest road cut slope were inquired. Ground surface is covered with the andosol of 1.5 m in thickness. The lower soil layer is composed of tuff breccia. There are two springs in road cut. One spring in andosol layer (spring A) has a few discharge when road cut slope were inquired. Another spring existed in tuff breccia soil layer. This spring B has few discharge when road cut slope were inquired.

[3] Hirusen C (Photo4) ; One spring position in bottom of the slope were inquired. Ground surface is

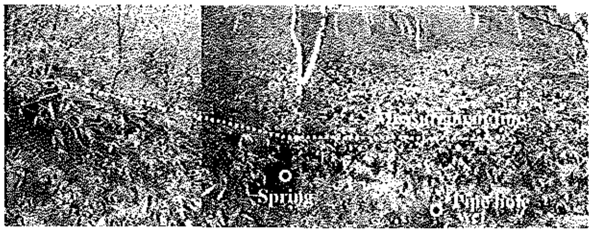

Photo 3 Soil exposure at the road cut in Hirusen B

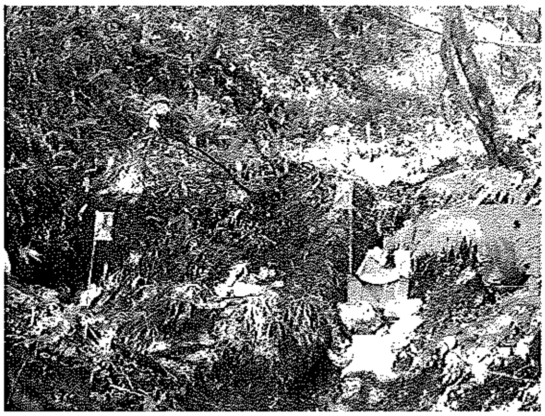

Photo 5 Condition around the spring in Hiru Valley

covered with the andosol of 2.0 m in thickness. The lower soil layer is composed of tuff breccia. There was the spring in andosol. And, spring occurred in heavy rainfall event or snow melting event. This spring has not discharge when slope were inquired.

[4] Misasa ; One spring position in bottom of the slope were inquired. Geological condition in this site was granite. Spring water exists in heavy rainfall event and snow melting event. This spring has much discharge when slope were inquired.

[4] Mt.Rokko ; One spring position in bottom of the slope was inquired. Geological condition in this site was granite. Spring water exists at all seasons. This spring had much discharge when slope were inquired.

[5] Kamitakara (Photo 5) ; Two spring position that developed in zero order channel of colluvium were inquired. Geological condition in this site was porphyritic. These springs had no water in dry season, however there was a small amount of discharge when inquired.

4.2 Prospecting method of water path

Water path in natural slopes were investigated according to the following procedure.

[1] The crossline was set up in the photograph 2-5 position.

[2] The measurement point is installed on the line at

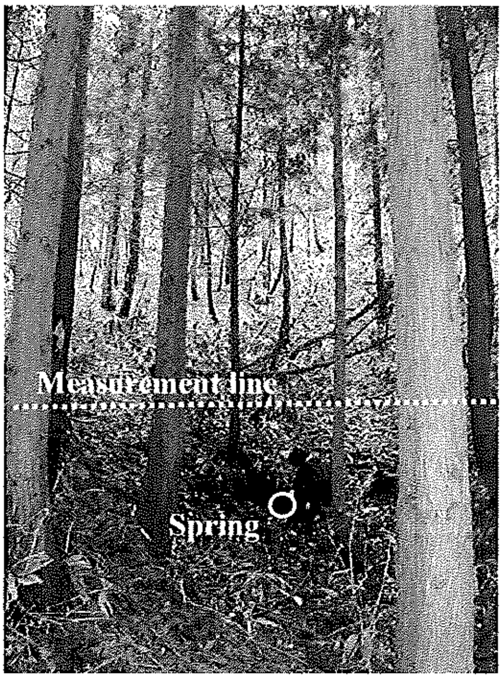

Photo 4 Condition around the spring in Hirusen C

intervals of 0.5-2m.

[3] Topographic survey is executed in water path position and measurement points .

[4] The underground sound was measured in each measurements point. Though the measuring method already mentioned, underground sound was measured by the frequency between 400Hz and 1200Hz to reduce the wind effect.

[5] The underground sound distribution chart was made from the investigation results.

4.3 Investigation results

Figure 10 shows the results of water path investigation. The solid line in figure shows the ground level, and white circle shows an actual spring water point. Black circle shows the underground sound that measured in the ground surface.

In all sites, underground sound was biggest on the spring point. And underground sound in measurement point has become small while going away from the spring point. This tendency is the same in case of two or more spring water exist.

These results in natural slope conformed to experimental results. And, It is interesting that there is a sound peak in the position where spring was not seen (Hirusen B, C).

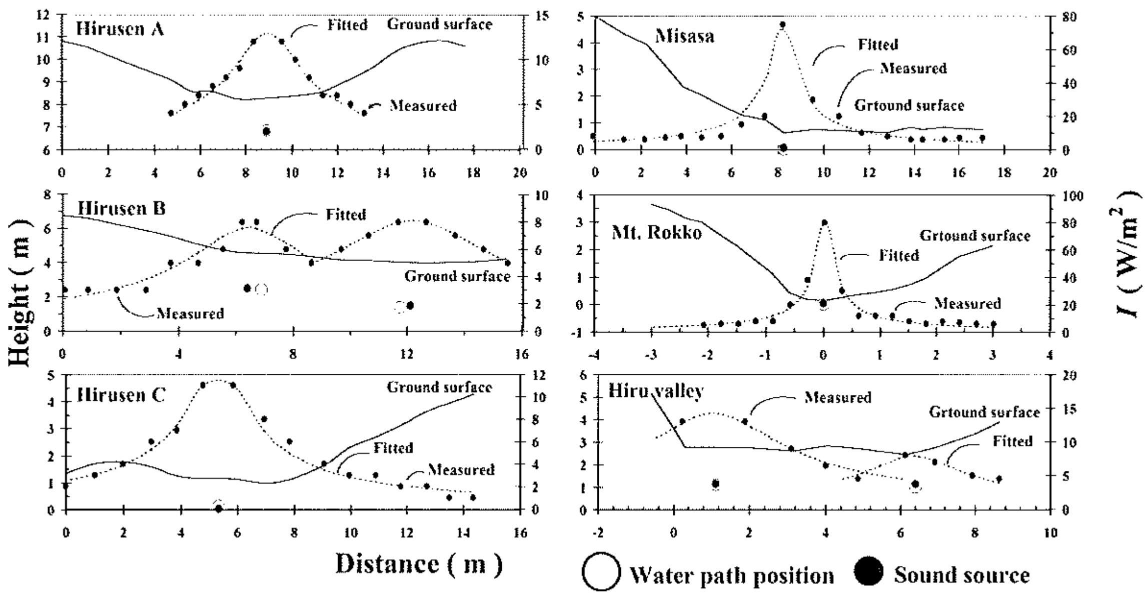

Fig. 6 Measurement results of underground sound and calculation results of water path position

5. Underground sound in collapse slope

An underground sound is inquired on the collapse site in the natural slope and the road cut slope. The relation between water path position and collapse position is investigated.

5.1 Study area and examination method

10 collapses that occurred in 4 natural slopes were investigated in Okayama prefecture. And 63 collapses that occurred in 40 roads cut slopes in Okayama prefecture. The location of study area were shown figure 1.

Collapse in natural slope was planting zone of Japanese cedar and Japanese cypress. Geological condition in all sites was granite. Width of collapses was from 2m between 16m, and depth was from 1m between 3m. Geological conditions of collapses in road cut slopes were granite, granodiorite and tuff etc. Collapses widths were from 2m between 30m, and depths of collapses were from 0.5m between 5m.

Water path position was estimated from underground sound pressure. The investigation was done according to the following procedures.

[1] In natural slope, measurement line was installed above 5m of scarp. In case of road cut slope, measurement line was installed upper 1m high from the road.

[2] Measurement points were installed at 1m or 2m intervals on this measurement line.

[3] An underground sound was measured at each points. And, the number of point and value of sound pressure were recorded.

[4] move to the next point

Hereafter, the last measurement point was measured by repeating the work of 1 -6.

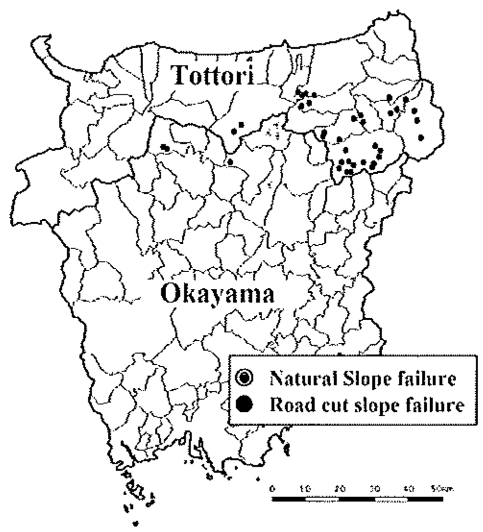

Fig. 7 Study area

5.2 Correspondence of collapse position and underground sound distribution

It was examined that the difference of an underground sound in collapse slope and non-collapse

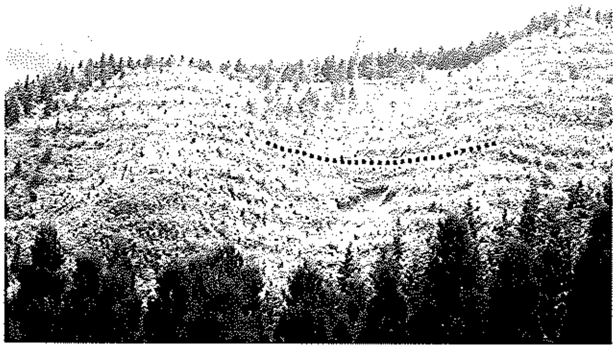

Photo 6 Collapse in natural slope A

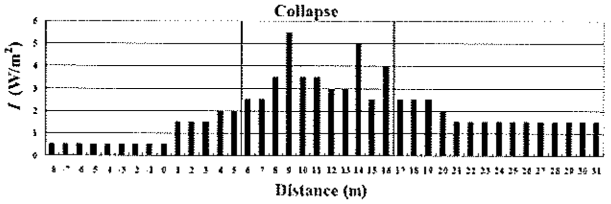

Fig. 8 Distribution of the underground sound in natural slope A

slope. Here. Some collapses were explained as the example.

a. Collapse in natural slope

Photograph 6-8 showed the appearance of the collapses in natural slope A-C. Measurement results of underground sound were shown at figure 2 to figure 5. The underground sounds were measured on interrupted line in each photograph. And, collapse positions were represented by gray hatch in each figure.

[1] Natural slope A (photo 6, Fig. 8)

Natural slope was catchments landform, and had one collapse. Width of collapse was 10m, depth was from 1m to 1.5m. Soil mass above the bedrock was collapsed. These were no spring when this site was inquired.

The underground sound in collapse position was bigger than another positions. And, Collapse position had 3 sound peaks. The collapse was divided into three blocks in photograph 6. And, each blocks was corresponding to each sound peaks.

[2] Natural slope B (photo 7, Fig. 9)

Three collapses were occurred in 14 age of Japanese cedar forest. The geographical feature was catchments. Collapse A was 12m in width, and 2.0m in depth. Collapse B was 16m in width, and 2.0m in depth. Collapse C was 10m in width, and 1.0m in depth. All collapses were occurred on the bedrock as a boundary.

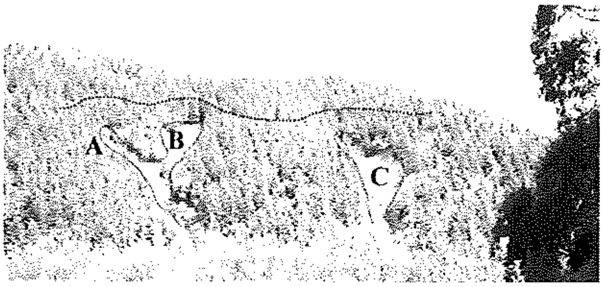

Photo 7 Collapse in natural slope B

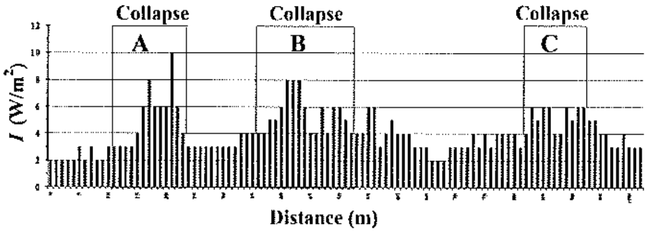

Fig. 9 Distribution of the underground sound in natural B

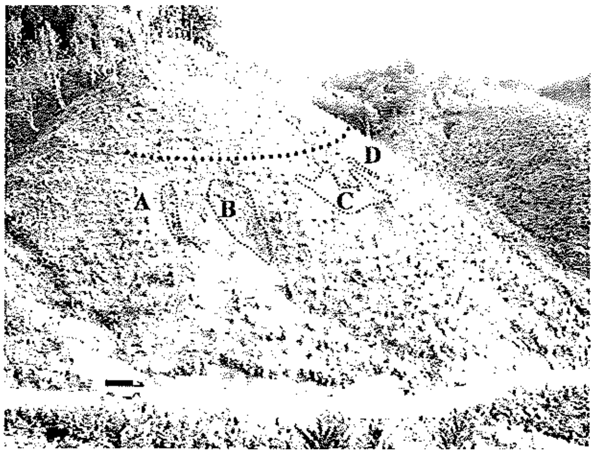

Photo 8 Collapse in natural slope C

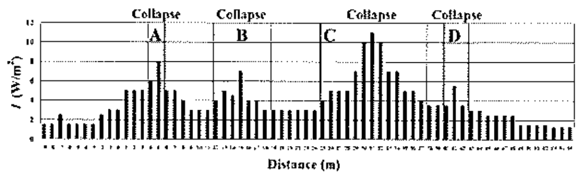

Fig. 10 Distribution of the underground sound in natural C

And all collapse had no spring.

The underground sound in collapse position was bigger than other positions. And, collapse B and C was divided two blocks in scarps. Correspondingly, these collapse had two underground sound peaks. The collapse positions and the underground sound peaks were adjusted even when the pond did not exist.

[3] Natural slope C (photo 8, Fig. 10)

Four collapses occurred in natural slope C. The geographical feature was ridge. Collapse A was 2m in width, and 1.0m in depth. There was one spring under the collapse. Collapse B was 6m in width, and 1.0m in depth. There were two springs under the collapse. Collapse C that was collapsed the soil mass above the bedrock was 12m in width, and 1.0m in depth. This collapse had no spring. Collapse D was 2m in width, and 1.0m in depth and also had no spring.

The underground sound in collapse position was bigger than another positions. And, there were two sound peaks in collapse B that had two springs

b. Collapse in road cut slope

Photograph 9-11 showed the appearance of the collapses in forest road cut slope A-C. Measurement results of underground sound were shown from figuration 11 to figuration 13. Collapse positions were represented by gray hatch in each figure.

[1] Road cut slope A (photo 9, Fig. 11)

Two collapses occurred in ridge of forest road. Collapse A was caused by typhoon No.23 in 2004. Collapse B was caused by typhoon No.21 in 2004. Collapse A was 30m in width, and 5.0m in depth. One spring and wet zone were detected in the investigation immediately after the collapse. Collapse B was 14m in width, and 1.0m in depth. One spring was detected in the investigation immediately after the collapse.

The underground sound in collapse A and B were bigger than another positions. And spring and wet zone in collapse A were corresponded with underground sound peaks. The under ground sound between collapse A and B was smaller than under ground sound in collapse A and B.

[2] Road cut slope B (photo 10, Fig. 12)

Two collapses were occurred by Typhoon 21in 2004. Collapse A was 3.0m in with, and 0.5m in depth. There was no spring in this collapse. Collapse B was 14m in width, 1.0m in depth. There was no spring in collapse B. The underground sound in collapse A and B were bigger than another positions.

[3] Road cut slope C (photo 11, Fig. 13)

Four collapses and two water erosions were occurred in planting road cut slope. Collapse C and D was made by grating crib works. Collapse A was 2m in width, 1.0m in depth, and had no spring. Collapse B was 4m in width, 1.0m in depth, and also had no spring. Collapse C was 6m in width, 1.0m in depth. Spring water occurred in heavy rainfall event in collapse C.

Photo 9 Collapse in road cut slope A

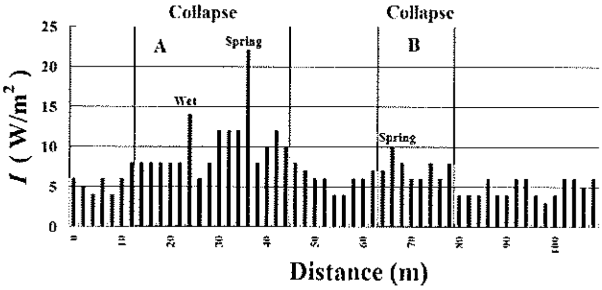

Fig. 11 Distribution of the underground sound in road cut slope A

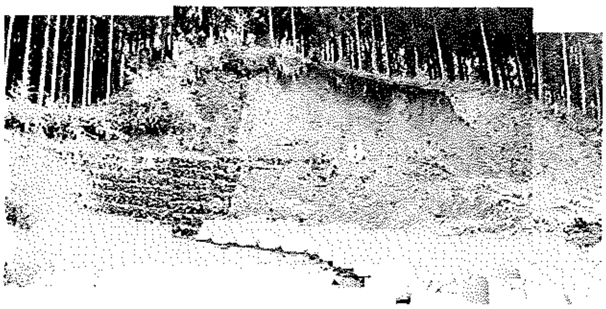

Photo 10 Collapse in road cut slope B

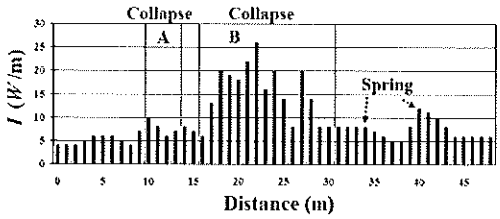

Fig. 12 Distribution of the underground sound in road cut slope B

Collapse D was 4m in width and 1.0m in depth. There is no spring in collapse D. Water erosions occurred in Position E and F.

Underground sound was big in each collapse positions and also big at position E and F that water erosion occurred

It was examined that correspondence distribution of underground sound and collapse position. As the result, there was clear relation between underground sound and collapse position. And, the underground sound in collapse position was bigger than another position. This phenomenon indicated that collapses in natural slope or load cut slope occurred at the water collect position. And, even if the slope did not collapse in big underground sound position, water erosion occurred in that position.

6. Monitoring of landform in underground sound peak

Underground sound in collapse site was measured. As the results, the collapses occurred at the position of underground sound peak. There were a few slopes that had not collapsed even if the underground sounds were the same as collapsed slope. Variance of slopes that had same sound peak in collapse position was examined.

[1] Road cut slope C

The underground sound in road cut slope C was measured on July 12, 2004. Photo 11 showed the slope at that time. After measurement, Typhoon No. 21 that approached to Tottori and Okayama area brought heavy rainfall on September 29-30 in 2004.

Figure 14(a) showed the appearance of precipitation. Peak of rainfall intensity was 30mm/hr. Cumulative rain precipitation was recorded 200mm.

Appearance of load cut slope C after the typhoon was shown Photograph 12. The road cut slope was collapsed by heavy rainfall of typhoon. Photograph 12 indicated that Collapse was occurred in left side of grating crib works. Collapse was 30m in width, and 1.5 m in depth. This collapse position was collated with the underground sound distribution chart (Fig. 15). The collapse was occurred in the part that had three peaks of underground sounds.

[2] Road cut slope D

The underground sound was measured on July 12 in 2004. After measurement, Typhoon No. 23 brought heavy rainfall in Tottori and Okayama aria on October 20-21, 2004. Figure 14(b) showed this precipitation result. Peak of rainfall intensity was 30mm/hr. Cumulative rain precipitation was recorded 250mm. Photograph 13 showed the appearance of road cut slope D before and after the typhoon approach. Cut slope was

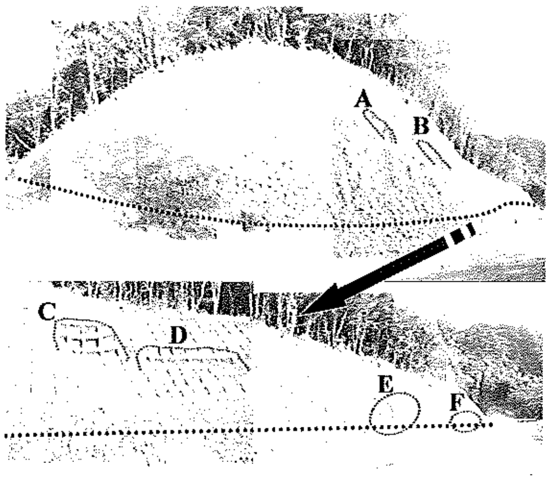

Photo 11 Collapse in road cut slope C

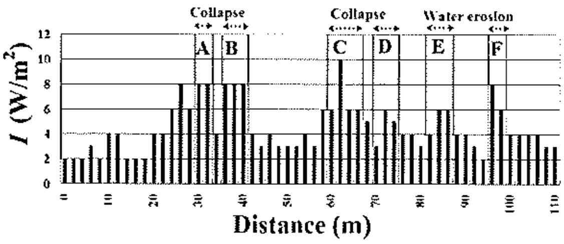

Fig. 13 Distribution of the underground sound in load cut slope C

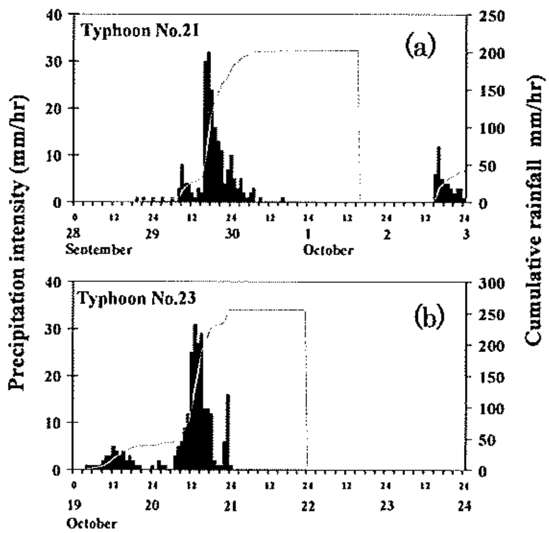

Fig. 14 Rainfall intensity and cumulative rain precipitation

collapsed by the heavy precipitation. Collapse was 10m in width, and 0.5m in depth. Figure 16(a) showed the underground sound distribution that measured before typhoon approached.

Figure 16(b) showed the position of collapses and

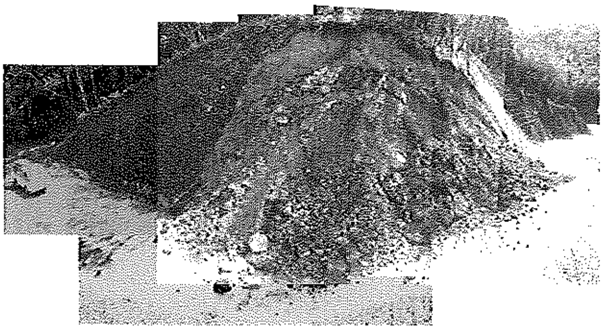

Photo 12 Road cut slope C after the Typhoon

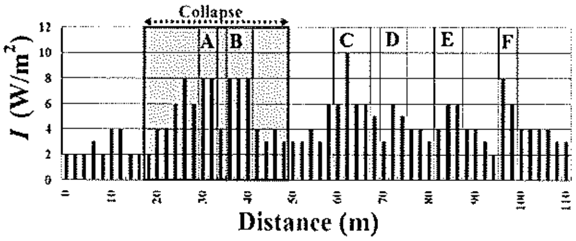

Fig. 15 Collapse position in road cut slope C

distribution of underground sound that was measured on July 12 2004 before typhoon approached. The pale hatch in figure showed the position where the collapse round had already been occurred on July 12, 2004. The dark hatch in figure showed positions in collapses and water erosions that were occurred by typhoon 23. Collapses occurred in big underground sound position.

The non-failure position that had big underground sound was collapsed by the typhoon. There is a part which underground water daily concentrates in the slope. And, water path position was collapsed by the groundwater that was supplied to torrential rains.

7. Conclusion

In this research, the method of detecting water path by an underground sound was proposed. And, this method was applied to the collapses sites in natural slope or road cut slope. Consequently, the following findings were obtained.

[1] The underground sound was biggest above the water path position. This phenomenon was confirmed in the experiment and natural slope.

[2] the underground sound in the collapses positions was bigger than other positions. Therefore, collapse occurred around the water path position.

[3] The non failure position that had big underground sound was collapsed by the next typhoon. There is a

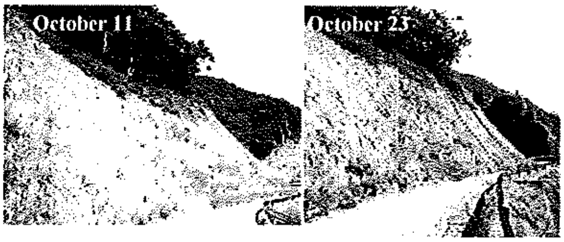

Photo 13 the appearance of road cut slope D before and after the typhoon approach

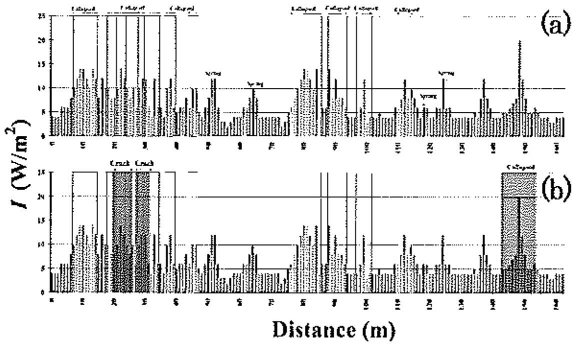

Fig. 16 Underground sound distribution and collapse position in road cut slope D

part which underground water concentrates drastically in the slope. And, water path position was collapsed by the groundwater that was supplied to torrential rains.

There were slopes that collapsed or did not collapse, even if these slope had similar landform and geological conditions. And, the reason cannot often be clearly answered. But in this study, it becomes clearer that the presence of the collapse is decided by the presence of underground water. When the collapses are investigated, it is necessary to note the presence of ground water.

References

Ohsaka, O., T. Tamura, J. Kubota, Y. Tsukamoto, 1992: Process study of the soil stratification on weathered Granite slope, *Jour. of the Japan Society of Erosion Control Engineering*, Vol.45, No.3, pp.3-12

Okimura, T. and S. Tanaka, 1980: Researchers on soil horizon of weathered Granite mountain slope and failured surface depth in a test field, *Jour. of the Japan Society of Erosion Control Engineering*, No.166, pp.7-16

Okunishi, K. and T. IIDA, 1978: Study on the landslides around Obara village, Aichi prefecture –Interrelationship between slope morphology, subsurface structure and landslide-, *Disaster*

Prevention Research Institute Annuals, Kyoto University, No.21B., pp.297-311
Tada,Y., T. Okumura, and T. Kubota, 2002: Examination of the influence of soil pipes on slope stability, *Jour. of the Japan Society of Erosion Control Engineering*, Vol.55, No.3, pp.12-20

地下流水音による崩壊発生位置の予測

多田泰之[*]・藤田正治[*]・堤　大三[*]・奥村武信[**]・小山　敢[***]・河合隆行[****]

[*]京都大学 防災研究所
[**]鳥取大学　農学部
[***]鳥取県 林業試験場
[***]鳥取大学大学院　連合農学研究科

要旨

本研究では新たに地下水流の発する地下流水音によって地中水みちの位置を検知する手法を開発し，その有効性について述べた。また，本手法を多数の崩壊地に適用した結果，すべての崩壊発生地では地下流水音が周囲の崩壊非発生地に比較して大きいことが分かった。また，地形変化をモニターした結果，豪雨によっていくつかの崩壊が発生したが，崩壊発生部位は全て地下流水音が大きい部位であった。これらのことから，①崩壊は地下水の集中する部位で発生すること。②新たに開発した本手法によって崩壊発生位置を予測する可能性が示された。

キーワード:水みち，地下流水音，崩壊位置